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THE PROBLEM OF COAL SUPPLY.*

BY

EDWARD W. PARKER,
Director, Anthracite Bureau of Information,
Wilkes-Barre, Pa.

THE subject assigned to me for discussion this evening by your secretary, and my friend, Doctor Owens, "The Problem of Coal Supply," is somewhat misleading, for I think I shall be able to show in a very few words at the outset that the problem in our fuel troubles is not one of supply but of production, transportation, and distribution.

The total area in the United States underlain by anthracite, bituminous coal, and lignite is about 460,000 square miles. Practically all of the anthracite is found in a relatively small area in the northeastern part of Pennsylvania. The productive part of this region is less than 500 square miles in extent, less than 0.11 of 1 per cent. of the total coal field, but the anthracite production to the close of 1915 has amounted to 2,626,500,000 tons, or nearly one-fourth of that of the entire United States.

The most important of the bituminous coal fields from a present producing standpoint, and so far as the quality of the coal is concerned, is the Appalachian region, extending from the northern part of western Pennsylvania and eastern Ohio to the central part of Alabama. The highest grades of bituminous coals (or

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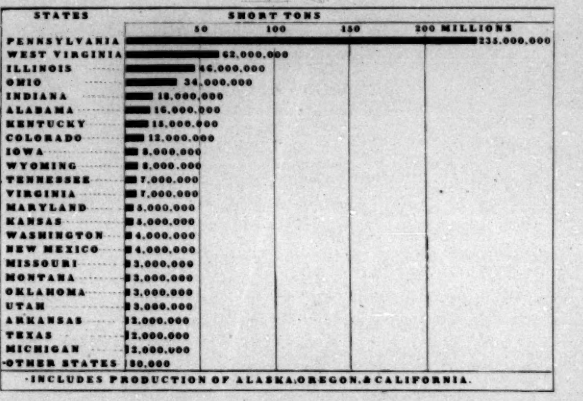
what we generally term semi-bituminous, because of their high carbon, low volatile, and consequently "smokeless" quality) occur along the eastern border of this region. The principal coking coal fields are also east of a line drawn through the centre of the region from north to south, as are likewise the better grades of steam coals and the Cumberland or Georges Creek (Maryland) smithing coals. Among the other higher grade coals well known to the coal trade that are produced on this eastern border of the Appalachian region are the Clearfield (steam), Connellsville (coking), Youghiogheny (gas), Somerset (steam), Pocahontas and



Production of coal in the United States by states.

New River (steam and coking), Jellico (domestic), Clinchfield (steam), and Warrior (steam and coking).

The coals of the interior province, extending from eastern Michigan on the north to Texas on the south, are of wider extent than those of the Appalachian region, but are decidedly inferior in quality to the coals of the Appalachian province. They possess little or no coking quality, though some of them, like the block coal mined near Terre Haute, Ind., have been used raw in iron furnaces. This quality of coal is largely already worked out. The combined contents of the Appalachian and interior provinces is something over 1,000,000,000,000 tons, of which a little more

than half is in the Appalachian fields and a little less than half in the coal fields of the interior states.

The coal fields of the Great Plains and Rocky Mountains far overshadow all the more easterly fields in extent and ultimate productivity, but in quality the most of the contents are much below even those of the interior province. There are some true bituminous coals, and two or three places where the bituminous coals have been locally changed to anthracite, but they are for the most part lignites and sub-bituminous coals, the latter being a grade between the true lignite and true bituminous coal. The Rocky Mountain and Great Plains coal fields embrace some 178,022 square miles and are estimated to contain 2,350,000,000,000 tons, or about two-thirds of the total supply.

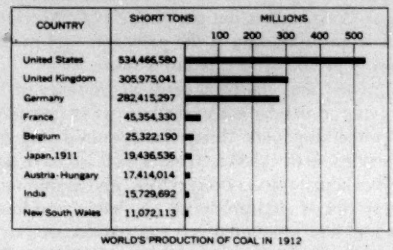
The productive coal fields of the Pacific coast are principally in the state of Washington, but the output is relatively small, and, as crude oil from California is the principal fuel in that section, they are hardly pertinent to this discussion.

It is estimated that the total original contents of these great coal fields, lying at depths not exceeding 3000 feet from the surface, were something over thirty-five hundred and fifty billion short tons, exclusive of Alaska, from which we have taken, to the close of 1916, about 11,500,000,000 tons, and assuming, as we do, that for every ton of coal produced one-half a ton has been lost, the exhaustion has amounted to 17,250,000,000, or, in other words, in a century of mining we have exhausted just about one-half of one per cent. of the original supply. At the rate of production in 1916, and assuming that we shall continue to lose half a ton for every ton mined, the storehouse still contains enough to last something like four thousand years. It does not look as if the problem were one of supply.

It must be remembered, however, that when we are speaking in these great figures of thousands of billions of tons as the total of our coal supplies, the great bulk of them consists of low-grade bituminous coals, and lignites which are contained in the Gulf, the Great Plains, and the Rocky Mountain provinces. Practically 70 per cent. of the total reserves are in these provinces, all of which are west of the Mississippi River. Only 15 per cent. is represented by the higher grade coals—the anthracite of Pennsylvania and the semi-bituminous and bituminous coals of the Appalachian region, and another 15 per cent. by the medium grade, non-coking coals of the Mississippi Valley states. And moreover,

it is upon these higher grade coals, of which we have the least in quantity, that we are making the heaviest drains. Of our total production at the present time, about 70 per cent. is from the anthracite fields of Pennsylvania and the bituminous coals of the Appalachian areas, 20 per cent. is from the states composing the interior province, and less than 10 per cent. from the great fields of the farther West.

Still, when we consider that even in these more rapidly exhausting areas in the East the quantity of coal yet remaining is about a thousand times the drain made upon it in 1916, we can hardly say that the problem is one of supply—certainly not of supply at the source. Even in the anthracite region, comparatively small as it is, and whose annual output to-day is equal to



WORLD'S PRODUCTION OF COAL IN 1912

what our total production of coal was in 1881—thirty-five years ago—there still remains 80 per cent. of the supply that was there when mining began. Anthracite, as you all doubtless well know, is now almost entirely a domestic fuel. It had at one time quite a vogue as a blast-furnace fuel, but that has passed. It is still used to some extent in the manufacture of gas and as a locomotive fuel for the first-class passenger trains of the anthracite carrying roads. Otherwise it is hardly known as a fuel except in domestic stoves and ranges and in the heating and operation of office buildings, hotels, and apartments, which is practically domestic use. Probably the first pinch will come in the high-grade semi-bituminous coals, the great bulk of which lies along the eastern border of the Appalachian coal field. They are relatively scarce, representing less than 2 per cent. of our total resources, and it is upon these that the drain is being made at a rapidly in-

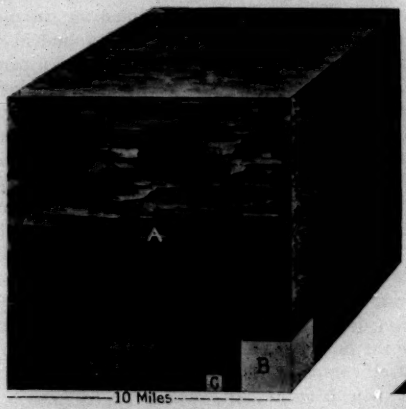
creasing rate. Campbell, of the Geological Survey, in his introductory chapter to a report on the coal fields of the United States says that these will be the first exhausted, and that such exhaustion may occur in the not very distant future. These are our best steaming coals, and their exhaustion will be a greater calamity to the country than the loss of all the anthracite, for coal of this kind has a greater efficiency and is adapted to more diverse uses than anthracite. We are rapidly consuming the cream and leaving the skim milk.

As I have said, practically all of the anthracite, or hard coal, as it is frequently called, which Nature has provided for the use and comfort of the people of the United States is found in a small area (less than 500 square miles) in the northeastern part of Pennsylvania. It has been estimated by geologists that when Nature had completed her task of depositing the coal, the contents of the field were about 16 times more than they were when man first began to mine and use it. These deposits, like those of other coals, passed through the various stages of forest growth, peat formation, lignite or brown coal, and then into bituminous coal. After these came tremendous earth movements by which the beds, formerly nearly horizontal, were bent and folded into mountains and valleys and the bituminous coal was changed to anthracite. The heat, and the pressure which caused it, during this period of stresses drove off the gases contained in the coal (and which produce the smoke when bituminous coal is burned), while the pressure itself compacted the material into the lustrous, dense, hard coal we know as anthracite.

After the mountains and valleys were formed, they were for millions of years subjected to the destructive wear of frosts and cutting streams, and finally were spread over by great glacier flows that came down from the north, so that by far the greater part of the mountains, containing most of the coal, were ground off and washed away until only remnants lying in the bottom of the great folds and containing only about 6 per cent. of the coal originally deposited were left for man to use. Nature seemed to regret her former generosity and took away the greater part of her gift. She was as wasteful as man is when in burning the fuel he gets only from 5 to 10 per cent. of the energy contained in the coal.

The conditions under which the vegetable débris was originally grown and deposited and the heat and pressure to which different

parts of the coal region were subjected were not everywhere absolutely the same, and so we find that there are some considerable differences in the qualities of the resultant anthracite. Where the heat and pressure were less the transformation was less complete. In these areas the coals are not so compact and are free-burning, but where Nature's action was stronger the change was more pronounced and the coals are harder and burn out somewhat less rapidly than the free-burning coals. All of them burn without smoke, however; all are clean and nice to handle; all are



A, our coal supply; *B*, total exhaustion; *C*, coal mined last year.

Pike's Peak, 14,108 feet above sea level.

Coal supply of the United States—1000 cubic miles.

practically free from dust, and all are absolutely safe in the stove, furnace, or cellar.

Anthracite, as it comes from the mines, is a confused mixture of large and small coal, rock, slate, bone, and dirt, which must pass through an elaborate process of manufacture before it becomes the article of commerce with which the consumer is familiar. The impurities of rock, slate, bone, and dirt must be separated from the coal, and the coal itself must be screened into the various sizes desired by the consumer, the pieces that are too large being broken up and made into marketable sizes. The fac-

tories in which this work is accomplished are known as "breakers," although the object is to secure the largest quantities of domestic sizes of clean coal with as little breakage as possible.

The percentages of the different sizes obtained vary somewhat throughout the several districts or regions, according to the character of the coal and the mining conditions, the average for the entire region being approximately, of prepared or domestic sizes (including lump and broken coal), 60 per cent., pea coal 12 per cent., and the smaller, or steam, sizes 28 per cent.

Conditions in the bituminous coal industry are widely different from those that control the production of anthracite. In the first place, the manner of occurrence, and consequently the methods of mining, are not the same. For the most part, the coal beds of the Appalachian and interior provinces lie relatively flat. There has been some movement, and some faulting, as the geologists say, but it has been chiefly in the way of elevation and depression, and none of these fields has been subjected to the same folding action as has occurred in the anthracite region. The mountains and valleys of the Appalachian bituminous fields are due to the influence of cutting streams, and where the coal lies above water level considerable quantities have been carried away, but, compared to the losses in the anthracite region, those in the bituminous fields have been relatively insignificant. In the interior province, where the country is low and flat, the coal beds are below water level and intact, except along the northern and western edges.

The mining problems in the production of bituminous coal are simpler than in the production of anthracite, and there is little or no preparation, the only process of "manufacture" being the passage of the coal over screens that may separate it into three or four sizes, usually three—lump, nut, and slack. And this is by no means general. A large part of the product is sold as mine-run, dumped from the mine cars into the railroad cars.

Bituminous coal is chiefly an industrial fuel—anthracite a domestic fuel. According to the report of the United States Geological Survey, 28 per cent. of the bituminous production is used for railroad fuel, 33 per cent. by the industrial steam trade, 15 per cent. in the manufacture of coke, and 16 per cent. for domestic use and small steam trade. The probability is that, out of the 502,518,682 short tons of bituminous coal produced in 1916, not much more was used for domestic purposes than there

was of anthracite, whose total production was 87,578,493 short tons, equivalent to 78,195,262 long tons.

I think I have shown that the great problem with which we are wrestling to-day, the problem of providing enough fuel, is not with the supply at the source. We must look for the trouble somewhere else. In the first place, I suppose it is hardly worth while for me to say that stupendous changes have taken place in the country within the last twelve months. It seems hardly possible to realize at the present moment that little more than a year ago the production of both anthracite and bituminous coal was in excess of the demand. Millions of tons of anthracite were in the storage yards of the big producing companies, and the problem the operators were then trying to solve was that of getting rid of the surplus and of the output that the mines were continuing to produce. Because of interruption to the normal ocean transportation and inability to secure vessels, the terminals of the great railroad systems became congested with freight consigned to the European countries that are now our allies, and cars that should have been engaged in bringing coal to market were tied up under load with no place to discharge. As a consequence of this situation, the coal in the yards of dealers gradually disappeared, as comparatively little fresh coal was coming in to take its place. The scarcity of equipment due to the congestion at tidewater terminals was more seriously felt in the bituminous coal fields than in the anthracite region. Bituminous coal has to be moved from the mines as fast as it is produced. If there are no railroad cars in which to load it, the mines must shut down until a supply of cars is at hand. So, too, if the markets are glutted and there are no buyers, production must stop, or at least be slowed up, until the surplus disappears. The great storage yards of some of the larger anthracite companies serve as an escapement or balance-wheel to that industry, but the bituminous mines are denied it. The difficulties in storing large quantities of bituminous coal vary with the kind of coal. Some of them have a tendency to ignite spontaneously when heaped in large piles, while all of them deteriorate somewhat rapidly on exposure to the atmosphere through the loss of volatile gases. Many kinds of bituminous coal also "slack," producing fine coal that is of inferior quality as fuel. The production of the different sizes or grades of anthracite is at a practically unchanging ratio. The proportions of egg, stove, nut, pea, etc., are about the same, year in and year

out, but the market demands vary radically. During the winter season, under normal conditions, the demand for the domestic sizes naturally increases over that of the summer, so that it usually occurs that during the summer months considerable quantities of these sizes go into storage, to be picked up and sent to market when cold weather approaches. It frequently happens that in the winter months the steam sizes are in excess and they go into the storage piles to take the place of the domestic coal shipped out. When the demand for all sizes falls below the ratio of production, the surplus goes to the storage yards, the mines are kept going and the miners are kept employed. It is cheaper in the long run to pay for the extra handling and suffer some loss in degradation than to shut down the mines.

Susquehanna Coal Company, Shamokin Division, Shamokin, Penna. Concrete block house for some of the Cameron Colliery employees.

Now, in the early part of 1916, as I have said, there were some millions of tons, mostly domestic sizes, of anthracite in storage, but this, like the coal in the dealers' yards, gradually disappeared, and then it suddenly dawned upon everybody that there was practically no coal in sight and that the householder, the manufacturer, the public utilities, and the railroads found themselves dependent upon the day-by-day production of the mines. Then came the long, cold winter that necessitated the continued use of coal for household heating purposes fully a month after furnace fires are usually abandoned. This condition was particularly in evidence in the Northwest, and the surplus of several hundred thousand tons of coal that is generally carried over from one year to another was entirely consumed. Moreover, lake navigation was more than a month later than usual in opening up, and the water carrying season has been shortened that much.

That section of the country is, in consequence of this and of other complications in lake traffic, in a much worse condition than other sections of the country that can be reached by all-rail haul in the winter.

Then came the long-deferred, but finally inevitable, entrance of the United States into the world war. Munition plants and other factories which had for two years been working overtime to supply the entente Allies doubled their energies, and the demand for coal and coke increased in proportion. Plants that in normal times were operated eight, or at the most ten, hours a day began working three shifts of eight hours each. I have been told that in the city of Bethlehem the demand for, and employment of, labor has increased so much beyond the places to accommodate them that one bed has been made to serve three shifts for as many men.

Our coal mines have for many years had a capacity for production of about 50 per cent. more than their annual output. That is to say, that in 1915, for instance, when they turned out something over 530,000,000 tons, they could have produced with the same complement of men and with a sufficient supply of cars about 800,000,000 tons, for the average number of days worked was only 209. By working 300 days in the year and eight full hours a day this figure could easily have been attained.

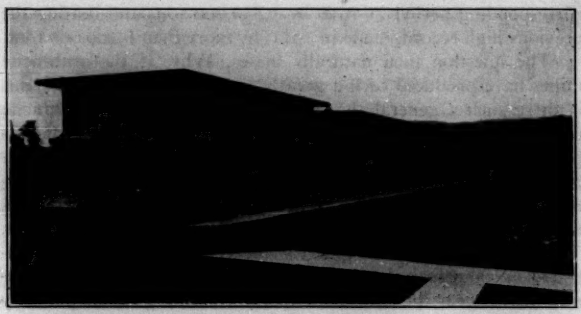
That they have not been able to meet the demand upon them has been due primarily to two causes, the more important of which has been the failure of the railroad companies to perform the extra service such a result demanded. Whether it was due to lack of foresight or whether it was due to causes beyond their control, the result is the same. They have not been able to respond to the call for cars or for the motive power the changed conditions required. Possibly locomotive and car builders have been too busy supplying foreign demand at highly profitable prices to accept orders at the prices which our railroad managers thought they could afford to pay, but, however that may be, the production of coal has been badly handicapped by lack of car supply. Operators have cried "Cars, cars!" but they say there are no cars, and many mines in the bituminous regions have been able to work only three to four days in the week for want of railroad cars. How serious this situation is may be judged from the report of a conference recently held between members of the National Association of Coal Operators and the Fuel Admin-

istrator, at which the statement was made that for the ten days prior to the conference the reduction of coal output below capacity had not been less than 400,000 tons per day.

I speak now of bituminous coal, for it is bituminous coal and its product, coke, that are needed for manufacturing fuel. Anthracite has not been subjected to the same untoward conditions. The anthracite carrying roads have more satisfactorily responded to the demands upon them and have transported to market during the first nine months of this year the heaviest tonnage ever produced in the same length of time. The shipments from the anthracite mines from January 1 to September 30 this year have amounted to 57,778,000 tons, exceeding the shipments in the corresponding period in 1916 by 7,850,000 tons and beating the previous high record, made in 1911, by more than 6,400,000 tons.

The question then naturally arises, Why, if the anthracite mines have produced such a greatly increased quantity this year, is there such a general shortage of coal through the anthracite consuming territory? I am not going to say that this shortage is psychological, but I do believe that there is more coal in the cellars of consumers to-day than ever there has been before in the history of the country. The trouble has been in the distribution, not by the mining companies nor the railroads, but to consumers. The available supply of coal for the coming winter is concentrated in comparatively few cellars. During the spring and summer of this year the anthracite operators, through their publicity organization, advised consumers to take warning from the experience of 1916 and to lay in their supplies early in the summer, and, in order to stimulate early buying, put into effect the customary spring and summer discounts, though they were convinced—and events have since proved—that all of the coal could have been sold at full circular price. Undoubtedly, most of those who could afford to, and who were forehanded, took good advice, and their cellars are stocked with a winter's supply, but also undoubtedly, and very unfortunately, the people of less means—and they are the more numerous—were misled by newspaper reports that when the government got in its work on the coal operators, coal carriers, and coal dealers there was going to be a great slashing of coal prices. Small consumers only had to wait and they would effect a material saving on their coal bills. Well, the Federal Trade Commission made a pretty exhaustive inquiry into the anthracite situation, with the result that when the President, on

August 23, announced the mine prices for anthracite, he practically adopted the Reading circular. The Federal Trade Commission not only investigated mine costs and prices; it also investigated and is still investigating the costs and profits in the conduct of the retail coal business. It found, it is true, that in some cases dealers had been exacting unreasonable profits, but the business as a whole was not doing injury or injustice to the public, and there has been no general slashing in the retail prices of anthracite. It was largely the poorer classes that were misled by these reports, and it is they unfortunately that point the modern moral of a certain parable with which you are all familiar—



Concrete City, Delaware, Lackawanna and Western Railroad.

their lamps, otherwise their coal bins, are unfilled. I am optimistic, however, and believe that we will get through this winter without much suffering, even among the poorer classes. Those who have their cellars full will not have to buy any more, or at least will have to buy very little coal, to see them through. As I have said before, more attention is being paid just now to the Northwest, in order that as much coal as possible may be sent to that section before lake navigation is closed by ice. After that pressure is removed, greater consideration can be given to the more southerly markets, and they will to a large extent be taken care of.

And let me here speak for a moment of the manner in which the anthracite production has been distributed from the mines.

The Anthracite Bureau of Information, maintained at Wilkes-Barre by the anthracite producing companies, and with which for the past two years I have been connected, has compiled some statistics of the distribution of the output in the last two years to four leading markets—New England, New York City, Philadelphia, and the lake ports of Buffalo and Erie. These statistics show that the shipments to New England for the first eight months in 1916 were 5,790,237 tons; this year they have amounted to 6,455,941 tons, the increase being 665,704 tons, or 11.5 per cent. The shipments to New York have increased from 12,666,650 tons to 13,912,384 tons, a gain of 1,245,734 tons, or a little less than 10 per cent., while to Philadelphia were sent, in 1916, 4,186,698 tons, and in 1917, 4,927,992 tons, the increase being 741,294 tons, or 17.7 per cent. On the whole, it can hardly be said that Philadelphia has any just cause for complaint. The lake ports had not fared so well, but even there there is no actual diminution in shipments, and by the time the lakes are closed it is believed that even the shortage due to the unusual consumption in the spring months will have been more than made up. I think the showing regarding the distribution to these markets is quite convincing that the increase of 16 per cent. has been equitably distributed.

Anthracite, as I have said, is now almost exclusively a domestic fuel, the relatively small amounts consumed by railroads and gas companies not being important factors under normal conditions, but, owing to the inability of the bituminous mines and the coke ovens to meet the demands put upon them by the manufacturing industries of the country, extra demands have been made upon the anthracite mines. In some cases powerful influences have been brought to bear seeking to compel the anthracite interests to divert their product from its legitimate and customary channels, in order to relieve conditions that have developed chiefly through the failure of the transportation companies to supply the needed cars to the soft coal mines, and not the least of the difficulties with which the operators are contending at the present time is the protection of their regular trade.

The entrance of the United States into the world war has placed additional obligations upon the operators of coal mines, both anthracite and bituminous. The munition and other plants that, while the United States was still a neutral, were manufacturing war materials for the Allies now have a preferred place in

the distribution of coal, because they are making the guns, the shells, the ammunition, the clothes, and other equipment for our own army and navy. They cannot be allowed to shut down; they must be provided with fuel. And then the government itself has become a very important purchaser and consumer of coal, and its demands have absolutely first call upon the output of the mines. The forts and cantonments in which our national army is being concentrated and trained must be kept constantly supplied with the coal necessary for heat and cooking. The demands from these are principally for anthracite, and to give you an idea of what

Concrete City house.

this amounts to, I may state that the requirements of one of these cantonments alone for the month of November amounted to nearly 12,000 tons. The Navy Department also required considerable quantities of anthracite, though its principal demands are for bituminous coal; in fact, while the anthracite tonnage required for all the government departments may be stated in thousands or hundreds of thousands, the demands for bituminous coal will run into the millions.

Even Nature seems to be determined to add to the demands made at this particular time upon the mines, as if their burden

was not already sufficient. I refer to a condition that has developed in Ohio and which should be relieved if possible. The failure of the natural gas supply is a serious matter to the people in that section. Most of the homes in the country and in the smaller towns are equipped with base-burning stoves, in which anthracite or natural gas can be used, but which are not adapted to the use of bituminous coal. And from them has come a Macedonian cry it is impossible not to heed. With the supply of natural gas cut off, unless the people can secure anthracite, it means the discarding of their base-burning stoves and the substitution of bituminous coal burning stoves to an extent which the stove dealers and manufacturers are not prepared to supply. It presents one of the most serious phases of the problem of coal supply.

The labor situation is another serious phase of the problem. Attracted by the higher wages being offered by munition and other manufacturing establishments, men have deserted the coal mines by the thousands. The call for men for the army and navy has taken other thousands from the mines. The average number of men employed in the anthracite mines under normal conditions is from 175,000 to 180,000. Reports to the Anthracite Bureau of Information show that the average for the last few months has been only a little more than 150,000 men. This means a shortage of nearly 25,000 mine workers, and yet in two recent months, June and August, the shipments have exceeded 7,000,000 tons, the only two instances in the history of the region —a really remarkable record. It is well, however, to sound a note of warning. The anthracite mines are at the maximum of their capacity. Any further depletion of the labor must result in a decreased output, and the problem will not be one of coal supply but of getting along with less. That may not be impossible. We have been accustomed to a bountiful supply, and at prices less than the people of other countries pay for their fuel. We have been profligate in its use, and it is now time to undertake a reform. You who are still living at home and not in a hotel or apartment may do your bit in helping to solve the problem of coal supply. The heating of your home should be brought down to a practical basis of efficiency. You should ask yourself whether or not you are getting a dollar's worth of heat for every dollar's worth of fuel you consume. Probably you are not. The fault may be with your stove or furnace or with the kind of

fuel you are using, or with your method of regulating the stove or furnace. Quite frequently that same faithful old stove or furnace is unjustly blamed, and it is in reality the method of regulation that is at fault.

Sometimes the combustion chamber is not sufficiently filled, or it may be too full. The top of the fire-brick linings in the range, cylinder stove, or hot-air furnace and the bottom of the feed-door opening into steam and hot-water boilers are the definite gauges by which you should judge the height of the fuel bed. Always fill the fuel space of your stove, furnace, or boiler accordingly, heaping the coal slightly in the centre. The fuel space should be filled twice a day in winter weather. The last time should be as late at night as is convenient. By feeding small quantities of anthracite to the fire several times a day, with attendant shakings, you lose in both economy and comfort. Shake the grate only until a bright light shows underneath, and do this only twice a day. Further shakings permit unconsumed coal to pass through the grate-bars. When the furnace is filled at night the fire should be checked or damped down and be ready to give a quick heat in the morning. Steam or hot-water boilers should have the fireplace filled with coal at least to a point level with the bottom of the feed-door opening, and one feeding should be sufficient for twelve hours if the drafts are properly adjusted. Once in the morning and once in the evening are the only times when attention is necessary under normal weather conditions. Ashes should be shaken down just before the furnace or stove is refilled with fresh coal. Keep the ash-pit empty. Do not let the ashes bank up under the grate. This not only prevents the proper circulation of air needed for combustion, but also tends to warp the grate-bars. Removing the ashes regularly once a day, even if only a small amount has fallen, is the best plan.

Efficient management of domestic stoves and furnaces will go far toward solving the problem of domestic fuel supply.

OCCLUDED GASES IN FERROUS ALLOYS.*

BY

GELLERT ALLEMAN,

Professor of Chemistry, Swarthmore College, Pa.,
Member of the Institute,

AND

CHARLES J. DARLINGTON,[1]

Department of Chemistry, Swarthmore College.

In view of all the elaborate and careful researches which have been conducted during the last forty years on the subject of occluded gases, some apology seems necessary for further work on this subject. From a careful search of the literature, the following observations in reference to previous work seem to be justified:

First.—The containing vessels used were porous in most cases —especially at high temperatures.

Second.—When gas flames were employed as a source of heat, the partial diffusion of such gases through the tubes added an additional error.

Third.—Practically all of the temperatures heretofore obtained were not sufficient to completely expel all of the occluded gases.

One of us (Alleman), in conjunction with C. Heyburn Jones, attempted some preliminary experiments, hoping to secure materials for containers which would not be open to the objections just indicated. This work was started in February, 1914.

Interest in occluded gases was aroused by an investigation one of us (Alleman) conducted, which had to deal with the bubbles formed around wire in wire glass. This was undertaken about four years ago. For a long time we were of the opinion that these bubbles were composed of carbon dioxide and emanated from the glass itself, the wire simply acting as the nucleus for the formation of the gas. While working at the plant and observing the glass plates as soon as the wire had been rolled into them we were impressed with the fact that the gas did not appear

* Concluded from page 357, vol. 185, March, 1918.

[1] We acknowledge, with appreciation, the assistance rendered by Mr. W. R. Gawthrop, of this laboratory.

next to the wire until after the wire had been in contact with the molten glass for several seconds. After this space of time, the wire suddenly brightened as if some chemical action had taken place, and bubbles immediately appeared on the surface of the wire. When glass was rolled at very low temperatures it was noticed that the amount of gas around the wire was not as large as when the glass was rolled at higher temperatures. It was also noticed that various wires were responsible for the production of more or less gas, and wires made of certain metals, notably platinum, copper, and nickel, when rolled into molten glass were almost free from this phenomenon.

The preliminary experiment which indicated that the wires occluded gases, and that these gases were given off in heating, consisted of a simple test with a glass tube and a piece of wire. The wire was inserted into the glass tube, one end sealed in, and the other, open end, attached to a vacuum pump. A vacuum was applied to this tube, and the tube heated by means of a Bunsen burner. The tube soon collapsed, and the wire was firmly imbedded in the glass. Under these conditions—namely, when the tube was under a vacuum—no bubbles appeared between the wire and the glass; whereas, when a similar tube was heated, but not subjected to the influence of a vacuum, bubbles appeared between the glass and the wire.

We wish to acknowledge the many courtesies extended to us by Mr. Walter Cox, president of the Pennsylvania Wire Glass Company, who furnished us with materials and granted opportunities for observation without which we should have been unable to continue this work

After the above-named investigation was completed, we determined to investigate the question of occluded gases in a more scientific manner than the limits of a technical research would permit.

Hard-glass tubes were first employed, but it was soon found that no glass known would withstand the temperatures required without melting. Porcelain tubes were next tried, but these became porous, evolved gases, and added additional complications to the subject. Tubes made of certain alloys were rejected for the same reason.

Quartz tubes were next employed, and these were jacketed and a vacuum placed on the outside as well as the inside of the tube.

It was determined that quartz was unfit for our experiments, because clear quartz vitrified at about 1100° C., and was found to be very porous at this temperature. In this connection we wish to detail an experience and to exhibit a picture of the actual tube employed. A quartz tube was wound with nichrome ribbon, surrounded with an iron jacket, a vacum pumped on the iron jacket and also on the quartz tube, and the tube heated (by passing a current through the nichrome ribbon) to about 1000° C. The tube contained no material, but gas was evolved from the tube, and this proved to be composed largely of hydrogen and carbon monoxide. The results obtained follow:

Gas	Analysis No. 1, 15 hours c.c.	%	Analysis No. 2, 63 hours c.c.	%	Total c.c.	%
Illuminating	0.0	0.0	0.0	0.0	0.0	0.0
CO_2	0.0	0.0	0.0	0.0	0.0	0.0
CO	.6	4.41	7.6	29.9	8.2	21.01
O_2	0.0	0.0	0.0	0.0	0.0	0.0
H_2	5.64	41.50	12.2	48.0	17.84	45.75
N_2	7.36	54.09	5.6	22.1	12.96	33.24
Total	13.60	100.00	25.4	100.0	39.0	100.00

FIG. 1.

Illustrating porosity of quartz at 1000° C. Quartz tube showing spiral of carbon in inside (dark line). This tube was wound with nichrome ribbon on the *outside*. The deposit of carbon was formed on the *inside* by the oxides of carbon, occluded by the nichrome ribbon, passing through the walls of the heated quartz tube, and their probable dissociation, to some extent. Tests for traces of chromium and nickel were negative.

The source of this gas could not be imagined at first, as it is improbable that quartz contains either hydrogen or carbon monoxide. The tube was removed from the furnace and examined. On the inside of the quartz tube, under the spiral made by the nichrome ribbon, a deposit of carbon was found (see Fig. 1). It is apparent that at a temperature of 1000° C. quartz is quite porous; that carbon monoxide or carbon dioxide passed through

the walls of the tube; that probably either or both of these gases dissociated to a slight extent, and that carbon was deposited. This gas must have been occluded by the nichrome ribbon.

This difficulty was not experienced, so far as carbon is concerned, when quartz tubes were wound with platinum wire. Under the conditions of an external and internal vacuum, however, it was found that platinum was somewhat volatile, and the temperature of the quartz could not be raised to such a degree as to evolve all of the gas contained in the iron without completely devitrifying the quartz. Although a number of experiments were carried out with quartz tubes, they were finally abandoned and special alundum tubes substituted. The results of the experiments with both kinds of tubes are given below.

It was impossible to secure alundum tubes which were impervious to gases at temperatures above 1000° C., but by means of alundum cement the porosity of these tubes was markedly decreased. The special alundum tubes were wound, placed inside an iron jacket, a partial vacuum (740 mm.) placed on the iron jacket, but a complete vacuum (nearly 760 mm.) maintained on the inner alundum tube before heating.

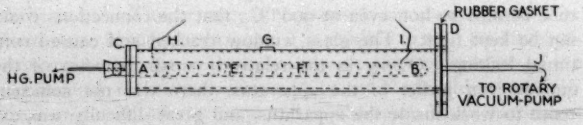
Desiring to secure higher temperatures than platinum resistances would afford, molybdenum wire was secured and used for our resistance. It will be remembered that molybdenum has a melting-point of about 2500° C., but that it readily oxidizes in contact with air. By means of this apparatus temperatures of 1900° C. were reached, which were sufficiently high for all purposes. It is believed that this apparatus furnishes a means of research in connection with the subject of occluded gases which is not open to the criticisms previously referred to.

A description will be given of several of the forms of apparatus used, and some typical results obtained by the use of each. It will be observed that the distinctive feature of all these furnaces consists in the fact that each heating tube is enclosed by a jacket, and, while a partial vacuum is maintained on the outside jacket, a vacuum, as complete as possible, is maintained on the inside tube. One of the first forms of apparatus used is shown in Fig. 2.

AB is a glazed quartz tube, 24 inches long and 1 inch in external diameter. It is closed at the end *B*, and contains 6

inches of transparent quartz in the middle, *EF*, in order that the sample may be observed during heating. The quartz tube is surrounded by a 3-inch iron pipe, *CD*, containing a window, *G*, formed by boring a 1-inch hole directly above the transparent portion of the quartz tube. This hole is closed by a piece of glass, air-tight connections being made here as elsewhere by the use of bakelite cement. The quartz tube is wrapped with 6 to 8 feet

FIG. 2.



of nichrome ribbon, having a resistance of 1.4 ohms per foot. This ribbon was previously heated in a vacuum in order to expel any gases occluded in it. The leads pass through the iron pipe at the points *H* and *I*. The outside chamber is connected to a rotary vacuum pump at *J*, and the inside chamber is connected to a mercury vacuum pump at *A*. Since the quartz tube extends several inches beyond the iron tube at this point, a rubber stopper is used as a connection without there being any danger of its

Weight of wire in grammes	Time of heat in hours	Volume of gas in cubic centimetres	Percentage composition of gas			
			CO	O_2	H_2	N_2
16.0362	3.0	31	5.48	0	48.15	46.37
13.7347	4.5	22.6	11.76	0	28.00	60.24
14.6718	5.0	26.7	16.40	0	51.60	22.00
11.3470	30.0	79.0	9.80	0	65.90	24.30
13.5516	6.5	26.2	19.85	0	41.90	38.25

burning. As a further protection, the end of the tube is water-cooled. The temperatures are read through the window, *G*, by means of a Wanner optical pyrometer.

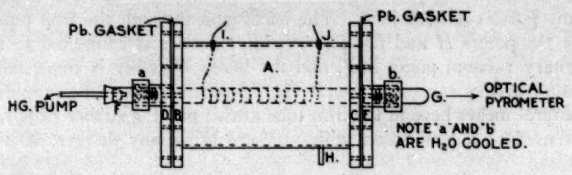
By the use of this apparatus several experiments were conducted with iron wire at temperatures ranging from 900° to 1000° C.

It can be seen that the ratio of the volume of hydrogen

obtained to the volume of the metal used varied from 3 to 30, depending upon the time of heating. In every case hydrogen was the largest constituent of the gas. This fact seemed to corroborate the statements of several of the earlier experimenters, who, it will be remembered, stated that, up to a low red heat, the gas evolved consisted mostly of hydrogen.

It developed that this type of apparatus was not suitable. No heat-insulating material could be placed between the outside and the inside tubes without closing the window. The outside tube became so hot, even at 900° C., that the connections could not be kept tight. The glass window cracked and caused continual leaking. Owing to the relatively small diameter of the outside iron jacket of the apparatus, there was not sufficient room to work inside the apparatus, and great difficulty was ex-

FIG. 3.



perienced in making connections. To obviate these drawbacks, a new type of apparatus was next designed and used. It is detailed in Fig. 3.

A is an iron pipe, 8 inches in diameter and 13 inches long. The flanges *B* and *C* are screwed to each end. To *B* and *C* the flanges *D* and *E* are bolted, air-tight connections being made by means of lead gaskets. These blind flanges *D* and *E* are bored through the middle, and into the holes are inserted 1½-inch nipples, on which are screwed caps containing 1-inch holes to permit of the insertion of the quartz tube *FG*. The nipples and caps are used in order to remove the packing for the air-tight connections as far as possible from the heating element, and also to give space for a water-cooling device. Various materials for the air-tight connections were investigated to determine

whether or not any were better for this purpose than bakelite, the latter being difficult to remove if any necessity arises for opening the furnace. Red lead and glycerine, Johns-Manville cement, okonite tape, and alundum cement were investigated. The best results are obtained by the use of bakelite cement at one end and a combination of a rubber stopper and okonite tape, covered with a layer of bakelite varnish, at the other end. All connections are covered with several layers of bakelite varnish. The quartz tube *FG* contains a transparent section 3 inches long at the end *G*. This arrangement possesses an advantage over the former one in that, in this case, it is possible to read the temperatures inside the tube, whereas before only the temperatures of the surrounding resistance wire could be read. In this case some insulating material can be placed in the space between the two tubes. A heating element of 20 feet of No. 22 platinum wire is wrapped around the middle of the tube for about 9 inches. Connections are made with the outside 110-volt, direct-current terminals, at the points *I* and *J*, in the manner illustrated.

The outer tube is connected to the rotary vacuum pump through *H*, and the quartz tube is connected to the mercury vacuum pump as in the previous apparatus. To serve as heat insulation, two or three layers of asbestos rope are wrapped around the quartz tube outside of the platinum wire.

In order that the test samples might be of very accurately determined composition, standard samples of iron and steel of varying percentages of carbon were obtained from the United States Bureau of Standards.

In the first determination 8.6604 grammes of basic open-hearth steel containing 1 per cent. carbon was used. The analysis of this steel, as furnished by the United States Bureau of Standards, is as follows:

Carbon	1.049
Silicon	.153
Phosphorus	.045
Sulphur	.028
Manganese	.405

DETERMINATION NO. 1.

Basic Open-hearth Steel—1.0 per cent. Carbon. Weight—8.6604 Grammes.

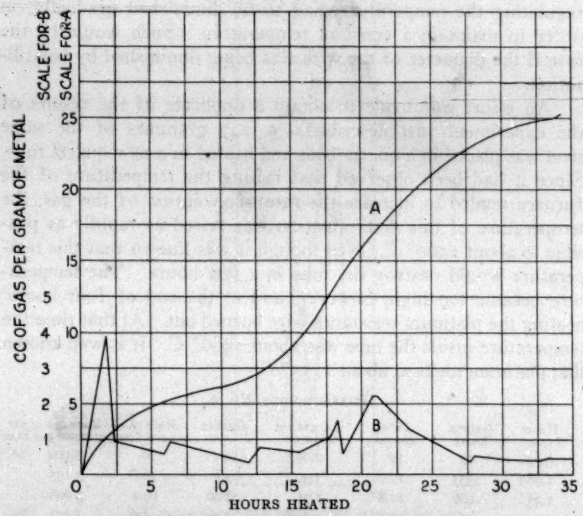
Hours heated	Gain in hours	Total gas, c.c.	C.c. gas per gramme	Gain in c.c.	Rate n c.c. per hour	Rate in c.c. per gramme per hour
1.75	1.75	25.2	2.91	25.2	14.4	1.661
2.25	.50	28.4	3.28	3.2	6.4	.739
5.75	3.50	40.7	4.7	12.3	3.52	.406
6.25	.50	43.8	5.06	3.1	6.2	.716
11.75	5.50	58.8	6.79	15.0	2.73	.315
12.75	1.00	65.8	7.59	7.0	7.0	.809
15.75	3.00	82.4	9.50	16.6	5.53	.639
17.75	2.00	99.2	11.44	16.8	8.4	.970
18.50	.75	108.4	12.52	9.2	12.25	1.415
19.75	1.25	114.6	13.21	6.2	4.96	.572
21.00	1.25	138.0	15.93	23.4	18.70	2.160
21.50	.50	147.2	17.00	9.2	18.40	2.120
23.50	2.00	169.6	19.55	22.4	11.20	1.292
25.75	2.25	183.0	21.13	13.4	5.95	.686
26.50	.75	186.8	21.55	3.8	5.07	.585
27.25	.75	195.8	22.60	9.0	12.00	1.385
27.75	.50	197.4	22.79	1.6	3.2	.3695
28.25	.50	199.8	23.04	2.4	4.8	.544
28.75	.50	202.2	23.35	2.4	4.8	.554
29.75	1.00	205.8	23.75	3.6	3.6	.416
30.75	1.00	208.3	24.05	2.5	2.5	.2885
31.75	1.00	210.4	24.30	2.1	2.1	.2425
32.75	1.00	212.6	24.55	2.2	2.2	.254
33.75	1.00	215.4	24.85	2.8	2.8	.323
34.75	1.00	218.0	25.17	2.6	2.6	.300

8.6604 grammes of this steel was placed in a platinum boat and heated. The variations in the rate of evolution of the gas are shown in the table and in the curves (p. 469). The gas obtained was collected and analyzed at six different stages. The results of these analyses are as follows:

Cubic centimetres gas	Time, hours	Temperature, ° C.	Analysis of the gas collected, per cent.				
			CO_2	O_2	CO	H_2	N_2
28.4	2.25	940	0.0	2.82	50	21.5	24.68
15.4	4.0	1046	1.52	4.0	48	31.0	15.75
		1242					
38.6	9.5	1332	0.0	3.88	58	23.7	14.22
64.8	5.75	1452	Analysis not made—gas escaped.				
22.4	2.0	1452	0.0	0.0	89.5	3.32	7.08
		1438					
48.4	11.25	1468	0.0	3.72	60.5	14.9	20.88
218.0	34.75		0.13	2.08	59.8	18.18	19.81

We thus find that over the space of 35 hours during which the metal was heated, 218 c.c. of gas, or 25.2 c.c. of gas per gramme of metal, or about 198 c.c. of gas per c.c. of metal, was evolved. Sixty per cent. of this gas was carbon monoxide. When the heating of the metal ceased, gas was still being evolved, but very slowly. Heating was stopped on account of the failure of the quartz tube, which had become devitrified at the high tempera-

DETERMINATION NO. 1.



A. Cubic centimetres of gas per gramme of metal.
B. Cubic centimetres of gas per gramme of metal per hour.

ture attained and had cracked. It was also discovered that the platinum boat, which contained the metal, had been attacked, the bottom being entirely destroyed. A considerable amount of carbon was found to have been deposited on the inner portion of the tube during the determination. It was concluded that this carbon was due to the decomposition of carbon monoxide, and that oxygen might be accounted for in the same manner.

Another interesting observation during the course of this determination was noted in connection with the behavior of the

platinum wire used as a heating element. When the quartz tube was removed from the outer iron shell it was found to be covered with a fine layer of glistening particles of platinum. Probably the presence of this platinum was due to the platinum volatilizing to a certain extent, a portion of the metal being condensed on the tube. This hypothesis is strengthened by the fact that, as the heating progressed, the amount of the resistance placed in series with the platinum wire, in order to provide a means for regulating the temperature, had to be diminished gradually, in order to maintain a constant temperature. Such would be the case if the diameter of the wire was being diminished by volatilization.

An effort was made to obtain a duplicate of the results of the experiment just described. 5.3247 grammes of the same steel was placed in a quartz boat and heated in a new quartz tube. Since it had been observed that raising the temperature of the furnace tended to increase the rate of evolution of the gas, the temperature of this determination was raised as rapidly as possible to about 1500° C., even though it was known that this temperature would destroy the tube in a few hours. The temperature became too high, however, and at the end of four hours' heating the platinum resistance wire burned out. At that time the temperature inside the tube was about 1500° C. It is well known that platinum melts at about 1755° C.

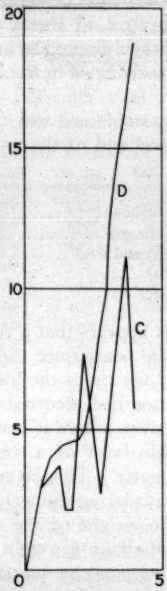
DETERMINATION NO. 2.

Hours heated	Gain in hours	Total gas, c.c.	C.c. gas per gramme	Gain in c.c.	Rate in c.c. per hour	Rate in c.c. per gramme per hour
0.75	.75	12	2.255	12	16	3.004
1.083	.333	17.6	3.307	5.6	16.8	3.155
1.25	.166	20.8	3.91	3.20	19.2	3.606
1.50	.25	22.2	4.168	1.4	5.6	1.051
1.75	.25	23.6	4.435	1.4	5.6	1.051
2.00	.25	26.4	4.96	2.8	11.2	2.083
2.25	.25	36.6	6.87	10.2	40.8	7.665
2.75	.50	44.0	8.26	7.4	14.8	2.778
3.00	.25	53.0	9.96	9.0	36.0	6.76
3.25	.25	67.8	12.71	14.8	59.2	11.12
3.50	.25	81.6	15.31	13.8	45.2	8.50
3.75	.25	91.2	17.12	9.6	38.4	7.215
4.00	.25	99.0	18.59	7.8	31.2	5.86

The curve shows the rate at which the gas was evolved. The two curves are interesting for purposes of comparison with the curves obtained from Determination No. 1. In this comparison

the large increase in the rate of the evolution of the gas with an increase in temperature is especially worthy of note. The gas was collected and analyzed in two lots. The results of the analyses are as follows:

DETERMINATION No. 2.



C. Cubic centimetres per gramme of metal per hour.
D. Cubic centimetres per gramme of metal.

Determination	Cubic centimetres gas	Time, hours	Temperature, °C.	CO_2	O_2	CO	H_2	N_2
No. 1.....	36.6	2.25	875 1485	0	0	67.7	16.81	15.49
No. 2.....	62.4	1.75	1470	1.92	0	86.9	8.61	2.57
Total...	99.0	4.00		1.20	0	79.8	11.65	7.35

When the tube was opened it was discovered that the steel had been completely fused, thus showing that a considerable

amount of time must be allowed for complete evolution of the gas, even after fusion.

From the figures given it is seen that, up to the time of the burning out of the platinum-wound furnace, the steel had evolved 99 c.c. of gas, or 18.59 c.c. of gas per gramme of metal, equalling about 130 c.c. of gas per c.c. of metal. Of this gas about 80 per cent. consisted of carbon monoxide, as compared with 60 per cent. of carbon monoxide obtained in the former experiment with the same steel.

The weight of the gas obtained was then compared with the loss in weight of the steel and of the quartz boat. The results are as follows:

	Grammes
Weight of the gas obtained	0.111239
Weight of the O_2 in the gas	.05327
Loss of weight of boat and steel	.0720
Loss of weight of boat	.0659
Loss of weight of steel	.0061

From these figures it appears that a reaction had taken place between the steel and the boat, since the loss in the weight of the boat was apparently ten times the loss in the weight of the steel. That such a reaction had occurred was proved by the fact that the bottom of the steel, where it had come in contact with the boat, contained a thin layer of a compound different from either the steel or the quartz. This layer probably consisted of a silicide of iron. By calculating the weight of the gas obtained and then subtracting the weight of the oxygen, both free and combined, in the gas, we obtain a weight which is less than the loss in weight of the steel plus the quartz boat. It would have been possible for the oxygen to have come either from the tube or from the air, due to a small leak in the tube, the outside vacuum having been broken several times during the course of the investigation.

The next determination (No. 3) was conducted on some Bessemer steel of the following composition:

	Per cent.
Carbon	0.084
Silicon	.005
Phosphorus	.094
Sulphur	.082
Manganese	.536

5.2364 grammes of the above steel was placed in the same quartz boat as was used in Determination No. 2, and the heating was conducted as in the previous cases. Since the quartz tube used in Determination No. 2 had become very badly devitrified, due to the high temperature, it was decided that, in this experiment, the temperature should be kept constant at 1100° C., a temperature at which devitrification takes place very slowly. The tables and curves following show the results obtained after heating the sample of Bessemer steel for 23 hours in a new tube. It can be seen, from the figures given, that the 5.2364

DETERMINATION No. 3.

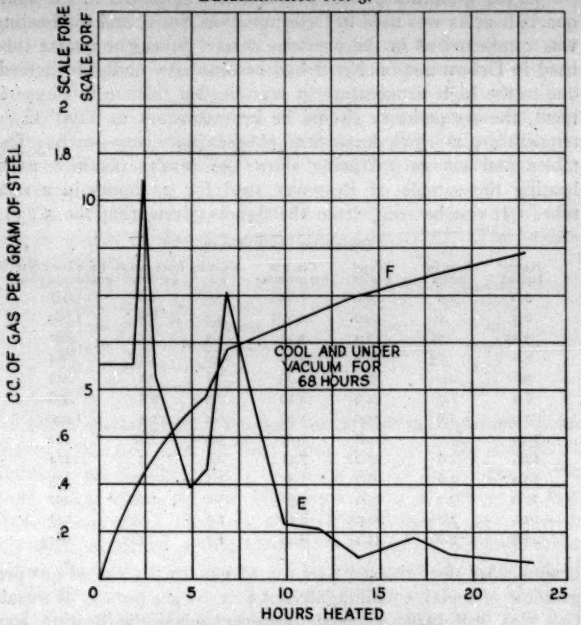
Hours heated	Gain in hours	Total gas c.c.	C.c. gas per gramme	Gain in c.c.	Rate in c.c. per hour	Rate in c.c. per gramme per hour
2.0	2.0	9.6	1.835	9.6	4.8	.917
2.5	.5	14.0	2.675	4.4	8.8	1.680
3.25	.75	17.4	3.32	3.4	4.54	.867
4.0	.75	20.0	3.82	2.6	3.47	.664
5.0	1.0	22.1	4.23	2.1	2.1	.401
6.0	1.0	24.6	4.70	2.5	2.5	.478
7.0	1.0	31.0	5.93	6.4	6.4	1.220
10.0	3.0	34.8	6.65	3.8	1.27	.242
12.0	2.0	37.2	7.11	2.4	1.2	.229
14.0	2.0	38.3	7.31	1.1	.55	.105
17.0	3.0	41.4	7.91	3.1	1.03	.197
19.0	2.0	42.7	8.18	1.3	.65	.124
23.0	4.0	44.4	8.49	1.7	.425	.0814

grammes of steel evolved 44.4 c.c. of gas, or 8.5 c.c. of gas per gramme of metal, equalling about 55 c.c. of gas per c.c. of metal. Gas was still being evolved, however, when the heating was interrupted. This gas was analyzed as a composite sample, the results of the analysis being as follows:

Cubic centimetres	Time, hours	Temperature, ° C.	CO_2	O_2	CO	H_2	N_2
44.4	23	1100	.68	1.57	26.15	43.40	28.20

It is seen that the gas evolved from this Bessemer steel at 1100° C. consists largely of hydrogen. In this case large amounts of carbon were found adhered to the inner portions of the tube, showing that some of the oxides of carbon had been dissociated. Even though the temperature had not been permitted to rise above 1100° C., it was discovered that the fine particles of steel were slightly fused to a solid, irregular mass.

DETERMINATION NO. 3.



E. Cubic centimetres of gas per gramme of steel per hour.
F. Cubic centimetres of gas per gramme of steel.

DETERMINATION NO. 4.

Another determination was then conducted on the same Bessemer steel (0.1 per cent. carbon). 5.9498 grammes of the steel was heated to approximately 1100° C. for 356.5 hours. During this time 319.3 c.c. of gas was evolved, which was found to be composed as follows:

Gas	Analysis No. 1, 47 hours C.c. gas	Per cent.	Analysis No. 2, 118 hours C.c. gas	Per cent.	Analysis No. 3, 198 hours C.c. gas	Per cent.
Illuminating	0.0	0.0	0.0	0.0	0.0	0.0
CO_2	.2	.33	.2	.47	.4	.88
O_2	1.0	1.66	.6	1.42	2.6	5.74
CO	16.0	26.68	8.3	20.40	7.6	17.20
H_2	26.1	43.50	26.9	63.70	17.35	38.30
N_2	16.7	27.83	6.2	14.01	17.25	37.88
Total	60.0	100.00	42.2	100.00	43.40	100.00

Gas	Analysis No. 4, 214 hours C.c. gas	Per cent.	Analysis No. 5, 293 hours C.c. gas	Per cent.	Analysis No. 6, 356.5 hours C.c. gas	Per cent.
Illuminating	0.0	0.0	0.0	0.0	0.0	0.0
CO_2	0.0	0.0	2.0	3.34	0.0	0.0
O_2	1.1	5.12	4.50	7.52	14.0	15.45
CO	3.4	15.80	8.20	13.70	Analysis not made	
H_2	6.61	30.75	7.64	12.75	Analysis not made	
N_2	10.39	48.33	37.46	62.69	Analysis not made	
Total	21.50	100.00	59.80	100.00	90.4	

Totals of All Six Analyses.

Gas	C.c. gas	Per cent.	
Illuminating	0.0	0.0	Analyses No. 1 to No. 6 inclusive
CO_2	2.8	.88	Analyses No. 1 to No. 6 inclusive
O_2	9.8	3.07	Analyses No. 1 to No. 6 inclusive
CO	43.7	19.09	Analyses No. 1 to No. 5 inclusive
H_2	84.60	39.93	Analyses No. 1 to No. 5 inclusive
N_2	88.00	38.42	Analyses No. 1 to No. 5 inclusive

Total—228.9 + 90.4 = 319.3

It will be observed that 90.4 c.c. of Analysis No. 6 was lost immediately after the oxygen determination had been made, and that, therefore, the remaining constituents of this gas are not known. From the figures obtained in Determination No. 4 it appears that the percentage of nitrogen evolved increased gradually with the time of heating. This fact seemed to indicate that there was possibly a leak in the apparatus. The amount of oxygen present as oxygen, as carbon monoxide, and as carbon dioxide was calculated for each analysis, and was compared with the amount of nitrogen present. The results of these comparisons follow:

Analysis	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Oxygen	35.5	44.4	28.5	21.2	19	....
Nitrogen	64.5	55.6	71.5	78.8	81	....

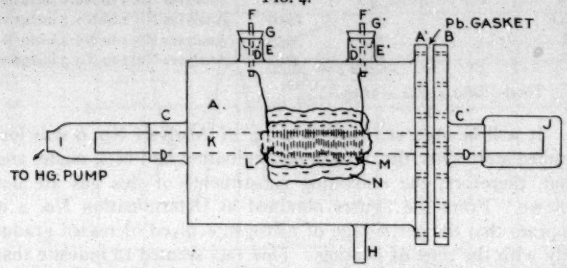
From these figures it can be seen that the oxygen and nitrogen were present in the latter analyses in almost the same proportion as in air. This fact suggested that the quartz tube was becoming porous with continued heating, and that some of the carbon monoxide and carbon dioxide present in the evolved gas was probably being formed by the combustion of the carbon in the steel.

From the evidence outlined above, as well as from a considera-

tion of other experiments not here described, we arrived at the conclusion that nichrome ribbon could not be used for heating purposes, in consequence of the fact that it contained large amounts of occluded gases and had a relatively low melting-point (about 1100° C.); that quartz was not available, because it devitrified at about 1100° C. and became quite porous; and that while platinum, after being heated in a vacuum, occluded practically no gas, its melting-point precluded its use for the maintenance of temperatures such as we required.

This necessitated the use of another material as resistance for heating purposes, and a tube and container which would withstand higher temperatures.

FIG. 4.



It was known that alundum would withstand much higher temperatures than quartz, and specially glazed tubes of this material were substituted for those of quartz. For a heating element molybdenum, with a melting-point of about 2500° C., was selected.

An important change was made in the iron shell surrounding the outside vacuum space. In the new apparatus all joints possible were welded, instead of being merely screwed together as in the previous apparatus. By this means sources of leaks were minimized. This apparatus is shown in the illustration above (Fig. 4).

A is an iron pipe, 8 inches in diameter and 10 inches long, on one end of which is welded the 2-inch nipple *C*, and on the other end the flange *A'*, to which is bolted the blank flange *B*, containing the nipple *C'*, which is identical with *C*. *E* and *E'* are 1¼-inch pipes, 1½ inches long, welded to *A*, and serving as

openings through which to make connection between the heating element and the outside current. F and F' are iron bolts held in place by alundum cement D and by the rubber stoppers G and G', on the outside of which are layers of bakelite and rubber cement. H is a ½-inch pipe, 1½ inches long, welded to A and serving as a connection to the rotary vacuum pump. K is the special alundum tube, 1 inch in internal diameter and 24 inches long. It is held in place at C and C' by the alundum cement D, on the outside of which is a coating of okonite tape and rubber cement. The heating element consists of 20 feet of No. 20 molybdenum wire L, which is wrapped around the middle of the alundum tube for 5 inches. This wire is connected through F and F' to the 220-volt, alternating-current circuit. On the outside of the wire is plastered a layer of alundum cement M, and on top of this are wrapped a couple of layers of asbestos rope N.

It being impossible to obtain gas-tight alundum tubes, even after having them glazed, it was necessary to make the outer vacuum space of the apparatus gas-tight, an operation which proved very difficult. Only after the protruding ends of the alundum tube had been inclosed in the glass coverings I and J were the leaks finally stopped. It was absolutely necessary that the apparatus should not leak before the current was turned on, as the molybdenum wire oxidized at red heat in the presence of the slightest trace of oxygen, and when such oxygen was present the molybdenum burned violently.

When the apparatus was apparently gas-tight, the current was turned on and a temperature of 1800° C. gradually attained and maintained for five minutes. A quantity of steam escaped from the apparatus, but all connections held, and the apparatus was free from leaks.

2.7091 grammes of Bessemer steel (0.1 per cent. carbon) was placed in an alundum boat lined with RR alundum furnished by the Norton Company, of Worcester, Mass. The boat was inserted in the tube and the temperature raised to 1650° C. Gas was evolved so rapidly that it could not all be collected. A sample taken when the evolution of gas had almost ceased proved to contain 95 per cent. nitrogen, 4.5 per cent. oxygen, and a trace of carbon monoxide. This proves that the nitrogen is held more firmly than the other gases, and is evolved finally only at very high temperatures.

Another determination was made operating on the same Bessemer steel (0.1 per cent. carbon). A sample of gas was collected when the temperature reached 1000° C.; another at 1250° C.; another at 1500° C., and the final sample taken at about 1675° C. The total amount of gas evolved from 7.162 grammes of steel was 201.2 c.c., equivalent to 28.1 c.c. per gramme, or 220 c.c. per c.c. of metal. The results of the analyses of these four samples of gas are as follows:

Analyses of Samples of Gas Taken.

Gas	At 1000° C.	At 1250° C.	At 1500° C.	At 1675° C.
Illuminants	.00	.00	.00	.00
Carbon dioxide	1.08	.62	.00	.00
Oxygen	2.4	3.07	4.28	6.25
Carbon monoxide	48.9	56.10	18.75	8.42
Hydrogen	21.16	15.08	4.20	1.10
Nitrogen	26.46	25.13	72.77	84.23
Total	100.00	100.00	100.00	100.00

GENERAL AND THEORETICAL.

It will be remembered that various authorities have arrived at the following conclusions regarding the effects of different gases in ferrous alloys:

The presence of occluded hydrogen apparently adds brittleness to a ferrous alloy, decreases its strength, and increases the hysteresis. The elasticity of such a specimen can be restored by removing the hydrogen.

The presence of occluded nitrogen increases the brittleness of a ferrous alloy, markedly affects its temper, and decreases its ductility. The strength is not markedly affected, but the hysteresis effect is increased. So far as the effect of occluded carbon monoxide is concerned, the experimental results are at variance, but it is apparent that the presence of carbon monoxide does not markedly change the strength, brittleness, or hysteresis of a specimen. J. E. Johnson, Jr., claims that the presence of oxygen in an iron is always attended with marked increase in strength of the specimen.

Our work has not progressed far enough to confirm all of these conclusions, but so far we have discovered nothing which would lead us to dispute these statements.

While it is true that gases exist in ordinary blowholes in the gaseous condition, it does not appear probable that ordinary occluded gases are present in metals in the gaseous state. If one considers the enormous pressures which these gases would exert, it appears that the alloy would not be strong enough to resist fracture. How then are these gases held? It might be possible that certain iron carbonyls, $Fe_x(CO)_y$, are present, but the iron carbonyls, which have been known and described, are all gaseous at the temperature of the solidification of iron. Of course, other carbonyls might be present. It is well known that iron carbides, iron nitrides, and iron hydrides exist. It is also true that iron oxides are present in most ferrous alloys. One can readily imagine a chemical reaction between iron oxide or iron carbonyl and a carbide of iron which would result in the formation of carbon monoxide or carbon dioxide. It is well known that hydrides of iron, on decomposition, yield metallic iron and hydrogen. It is also known that carbon dioxide and carbon monoxide are dissociated to an extent at high temperatures and yield carbon and oxygen; or, in the case of carbon dioxide, oxygen and carbon monoxide might result.

Mr. J. E. Johnson, Jr., has recently called attention to the fact that the presence of oxygen in charcoal was responsible for the superior qualities of charcoal iron, and states that he obtained oxygen from these high-grade irons. Whether or not the oxygen resulted from the decomposition of the oxides of iron or oxides of carbon has not yet been determined.

It has been observed that ferrous alloys made in electric furnaces, especially alloys particularly intended for tool steels, possess remarkable properties over the same alloys when produced in crucibles where the temperature is not as high as that attained in the electric furnace. It has also been determined that when these alloys are heated under the influence of a vacuum products possessing remarkable properties are secured. All this goes to show that the presence of certain gases exercises a deleterious effect on these alloys.

It is interesting to note that when iron is placed in an acidulated solution and made cathode it readily absorbs hydrogen. Curiously, this takes place below what is known as the decomposition voltage, at which point hydrogen and oxygen would be set free. If one connect a voltmeter and an ammeter in the circuit

and apply a pressure below the decomposition voltage of the solution, one will notice that the ammeter indicates a flow of current and yet no gas is evolved. It is apparent that energy is being used up, and it is difficult to explain what becomes of this energy. Since it has been shown that hydrogen is absorbed by the iron, under these conditions, it is apparent that the energy requirement has been accounted for. Under these conditions the iron changes in molecular structure, as can be shown by micro-photographs.

This work is being continued, and consideration is being given to the physical changes incident to the removal of occluded gases from ferrous alloys. Tests on the samples, before and after treatment, involving (*a*) strength, (*b*) electrical properties, and (*c*) micro-structure, are in progress.

CONCLUSIONS.

1. We have constructed a gas-tight vacuum furnace, capable of continuous service at temperatures of approximately 1900° C.

2. By means of this apparatus, all the gases occluded in ferrous alloys may be removed and collected.

3. It appears that the gases are evolved in the following order: hydrogen is most readily set free, carbon monoxide comes next, and nitrogen seems to be held most tenaciously.

4. Whether oxygen is the result of the decomposition of various oxides of iron or the dissociation of carbon monoxide or carbon dioxide has not been determined.

5. We have shown that ferrous alloys may occlude relatively large volumes of gases—in some cases equal to about 200 times the volume of the metal.

6. We suggest that in addition to the ordinary functions of metals like aluminum, tungsten, chromium, manganese, titanium, silicon, etc., when placed in ferrous alloys these elements may act as a catalytic agent and either prevent the occlusion of large quantities of gases or aid in the elimination of such gases at lower temperatures than would ordinarily take place.

7. We have shown that the removal of gases from ferrous alloys markedly changes the micro-structure and increases the density of the alloy.

A NEW THEORY OF PLATE SPRINGS.*

BY

DAVID LANDAU and PERCY H. PARR.

PAPER I.

PROBABLY the first paper of historical importance in connection with the study of the strength of materials, which influenced the work of the elasticians of the seventeenth and eighteenth centuries, was that published by the famous Italian astronomer and physicist, Galileo Galilei, in 1638.

Galileo's paper was the forerunner of several others which were published, dealing with the strength and rupture of beams; it was Galileo who found that a "solid of equal resistance" must have a parabola for its generating curve.

English investigators speculated much upon the nature of bodies which were elastic, frequently quoting the Scriptures as authority for their deductions and reasonings. A curious example of these "speculations" into the cause of elasticity may be found in a paper by Sir William Petty on "The Discourse made before the Royal Society concerning the use of Duplicate Proportions; together with a New Hypothesis of Springing or Elastic Bodies" (London, 1674). The author describes a complicated system of atoms, which he endows with polar properties, and even sexual characteristics, in order to explain his theory.

Modern conceptions of elasticity no doubt began with Robert Hooke. In a work published in London in 1678 he informs us that eighteen years previously he had first formed his theory of springs. He purposely refrained from publishing his theory, as he was anxious to obtain a patent for a particular application of it. His Anagram, which concealed his theory, is too well known for repetition here; it need only be remarked that the clarity and generality of his statements lead us to say that Hooke is well deserving of the place he occupies in the history of elasticians of the first rank.

Chronologically, the next elastician of note was Mariotte; he was the first to recognize that in a beam subject to flexure one-half of the fibres are compressed, while the other half are

* Communicated by the Authors.

extended. The term "fibre stress" must have had its origin about this time. Mariotte's work was published in Paris during 1686, and shortly thereafter G. W. Leibnitz stated that the stresses in the fibres are proportional to their extensions, thus applying Hooke's Law to single fibres.

Varignon, whose work was published in Paris during 1702, and Parent (Paris, 1710) studied the form of solids of uniform resistance; James Bernouilli's work must be mentioned in passing.

Sir Isaac Newton's work in the cause of elastic studies is, so far as concerns us, of only passing interest; his brilliant efforts in the domain of mathematics, on the other hand, influenced every field of scientific investigation, and ours none the less. The greatest investigator of the Newtonian period, and probably Newton's equal, was the famous mathematician Euler. Lagrange, in 1771, published a paper of some interest dealing with springs.

A paper by James Jurin, "On the Action of Springs," in the *Philosophical Transactions for 1744*, deals with the application of Hooke's Law to a special case.

Coulomb's published work in 1784 on "Torsion Springs" referred to metallic wires, and his first paper, published in 1777, dealing with the torsion effects on hairs and silk fibres, while not immediately related to our present paper, had a general stimulating effect on investigations of the general theory of elasticity.

Thomas Young, the English physicist, gave, in 1807, his first exposition of what we now call the "modulus of elasticity," or "*E*." Young was not a mathematician, and his statements often lacked the clarity of exposition and generality which we get from mathematicians.

The modern theory of elasticity may be said to begin with Navier (1785–1836), who, in 1820, analyzed the flexure of rods and solved the problems relating to the reaction of flexible bodies for which the elementary statics afford no solution.

Poisson began those portions of his elastic researches which concern us in 1814; and it has been said of him that there was hardly a problem in the domain of the elastic theory which he did not in some way or another investigate; his nearest equal was Cauchy.

Mechanical engineering began to demand much from elas-

ticians about 1840, and we find thus, as a result, the work of Poncelet on the "Theory of Resilience" which answered one of the demands. Lame and Clapeyron, studying the strength of iron used in bridges, founded, as a result of their practical studies, a most beautiful analysis in the field of elastic theory; their work greatly influenced all the later investigators. During the period 1840–50 appeared the works of Seebeck, Morin, Masson, Smith, and Newman, all of which are of sufficient importance to be mentioned here.

The greatest investigator, from our point of view, who combined practical knowledge with analytic ability of the highest order, and applied both to the study of the leaf spring, was, without doubt, E. Philips. Even at this late day, however, little is known of his work—even in his own country—France. An engineer by profession, yet an analyst of the most brilliant type, he alone attacked the problem of the plate spring in a truly scientific manner, and solved some of the most important problems requiring mathematical investigation. His researches were published in 1852, and almost every work on applied mechanics published since, which deals with the plate spring, has been based, to a greater or less extent, on his researches.

His paper, entitled "Memoire sur les Ressorts en Acier Employés dans le Material des Chemins de Fer," appeared in the *Annales des Mines*, Tome I, 1852, pp. 195–336.

The Academy of France appointed a committee, consisting of MM. Poncelet, Seguier, and Combes, to investigate Philips's work; they reported concerning this work as follows: "*Le Travail de M. Philips sera fort utile aux ingénieurs et aux constructeurs, qu'y trouveront des régles rationelles et d'un application facile pour les établissements des ressorts capables des satisfaire, aux la moindre depénse de matière, à des conditions données de flexibilities et de résistance.*"

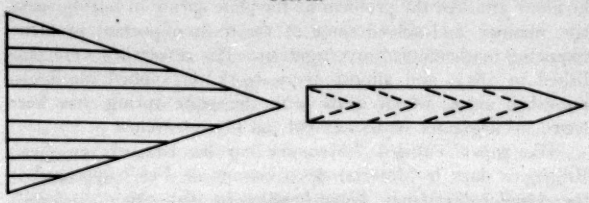
While there is no question as to the excellency of the work of Philips and its marvellous analysis of such a difficult problem, yet we do not quite agree with the committee's report. That the essence of the work of M. Philips may be "easily applied" to practical problems is a statement somewhat overdrawn; we confess, after a very careful and serious study of his memoir, that the applications of his equations are, in nearly all cases, most difficult, and, with the exception of a particular case, his expres-

sions are outside of the range of practical utility. This does not vitiate, however, the scientific importance of this work. Philips published other papers, but the one mentioned is, for the present, the most important.

In 1880 a graphic application of Philips's work was made by Lèvy Lambert: the graphs given cover only special cases.

In 1865, A. Ritter published his "Lehrbuch der Technischen Mechanik," the third edition of which appeared in 1874. This contained, probably, the first text-book treatment of the plate spring. We mention this work as being a sample of the text-book treatment of the subject of the leaf spring which is often given at the present time. Ritter himself seems to have taken out only one special case of Philips's. Ritter applies the Bernouilli-Eulerian theory of beams to a cantilever having a

FIG. A.



constant thickness in the vertical plane of flexure, and finds that in a horizontal plane the beam must have the form of an isosceles triangle. He therefore builds a leaf spring formed from a series of leaves obtained by cutting the triangular cantilever, by placing the several plates as indicated by Fig. A. He pointed out the fact that each lamina, at the pointed end, presses on each succeeding lamina with a force P, equal to the load P. The result, naturally, is that each lamina, except the shortest, acts as a cantilever, with a load P at its apex and with a reactive supporting load P at the end of the next shorter lamina. The solution of this problem is then, of course, quite simple. No proof is offered of this exposition, and we suppose that he assumed Philips's work would answer the case in the affirmative. Ritter added nothing new to the subject, although his work has been copied widely, as he had probably copied Philips's.

Ritter's work is of limited value, though correct, as we shall

show later on, in so far as it deals with a special case; its limits have not been pointed out by any writer since his time, with possibly the one exception—Henderson.[1] Henderson, however, only added to Ritter's work by introducing "constants" for "full length" plates: he did not question the accuracy of Ritter's work, nor did he state the limitations of his own applications. A better attempt was made by E. F. Morrison,[2] although Marcheseau indicated a knowledge of this same idea in 1909.

Reuleaux, who in 1857 published his "Constructeur," merely expounded a particular case of Philips's; indeed, Reuleaux has too often been credited with originating equations which were the work of Philips.

As late as 1877, Philips's countrymen gave short abstracts of his work for the engineering fraternity, and among the best of these is that of Albert de Fierlant, who seems to have well understood his master. The last work of de Fierlant, published in 1889, is an excellent short exposition of Philips's special case.

No particular work of great importance seems to have been published since 1850, if we except the recent one by Paul Brennier, which treats of some new phases of the problem, and indicates briefly the inadequacy of Philips's treatment of the general subject. The work of Brennier is very interesting and deserves the careful study of the specialist.

Briefly, the foregoing remarks cover the history of the theory of leaf springs up to the present time. And for the reader who is interested in a critical study of the history of the theory of elasticity, we recommend the careful perusal of Todhunter and Pearson's "History of the Theory of Elasticity." Having outlined the work of the previous investigators, we make no apology for now introducing our own researches.

The study of the particular problem with which the present paper is concerned was commenced by us nearly sixteen years ago; the research was carried on intermittently, and some of the fundamental relations to be treated in the next instalment were discovered but a few years ago.

During the last ten years we have searched, often with the assistance of many others, through the technical literature of the Old and the New Worlds, in order to discover what researches,

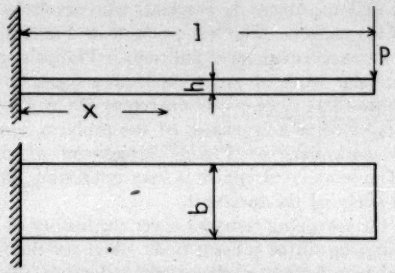
[1] G. R. Henderson, *Trans. A. S. M. E.*, vol. xvi.

[2] *Machinery Eng.*, ed. January, 1910.

if any, had previously been made by the earlier mathematicians and engineers which resembled our own. So far we have found but a single paper of importance, that of the famous French mathematical engineer, M. Philips, who, as mentioned in our historical *résumé*, made a study of the leaf spring [3] initiated on lines akin to our own; his theses, however, gave the mathematical relations in such complex form as to be of but slight use to the engineer and designer. The theory of Philips was not developed to an extent and direction which is in any way comparable with our own researches.

"The prevailing and generally accepted hypothesis on which is based the so-called 'scientific' design of plate springs is only a slight modification of the most elementary concepts and analyses

FIG. 1.



of the early teachers of theoretical mechanics." We shall show that their hypotheses are totally inadequate to explain the complete phenomena of leaf-spring action, and that, without the complete analysis, which our theory enables us to make, no true scientific leaf-spring design is possible.

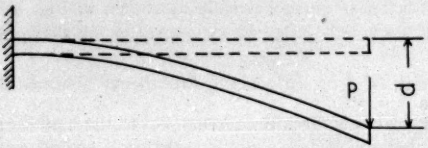
The application of the results of our investigation to practice has resulted in springs having an endurance, or life, far greater than usually obtained, and our springs have been a revelation even to those skilled in the art of spring making; in fact, on more than one occasion we have been charged with obtaining the enormous endurance shown by springs designed in accordance with our theory by some mysterious heat applications during the thermal treatment.

[3] *Annales des Mines*, 1852, 1, 195.

In order to lead to a complete understanding of our theory of the leaf spring it seems best to explain first, in as elementary a manner as possible, the prevailing commonly accepted theory of to-day. Our exposition may be somewhat different from some of those given in the text-books on applied mechanics, but the essentials and the results are the same.

Consider a single leaf as shown in Fig. 1, having a length l, a constant thickness h, and a constant width b; fixed at one end and subjected to a load P at the other end. Under these conditions the plate will deflect a distance, say d, as shown in Fig. 2. Of course, we assume in this exposition that any leaf spring may be considered as a beam encastre at one end and loaded at the other, as is the case with a cantilever spring; other springs (such as semi-elliptic springs) may, if desired, be considered as beams supported at the ends and loaded at the centre; the final result,

Fig. 2.



however, is exactly the same as if they are considered as two cantilevers joined at the points of encastrement. It suffices, therefore, to consider the case of the cantilever.

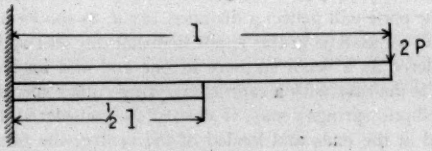
Suppose, now, that we arrange some suitable mechanism which shall vibrate this simple, one-leaf spring through the distance d such a number of times as shall cause it to break. Clearly, the fracture will occur at the point of fixation, for the bending moment, which is evidently $P(l-x)$, there attains its maximum value Pl; and, as the section of the leaf is uniform, the stress is a maximum at the same section as the bending moment.

The number of vibrations required to break the one-leaf spring having been determined, we may now propose the problem of constructing a spring to carry twice the load, or $2P$, and to deflect the same distance d, and also to withstand the same number of vibrations as before. How should we, in accordance with the present-day theory, make a spring to fulfil these requirements, it

being understood that the length l must not be altered? The answer of the present-day theory is given by Fig. 3.

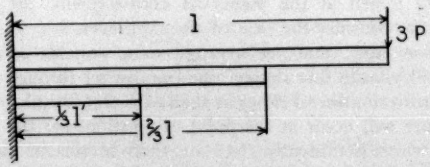
A second leaf, called the short leaf, and in this case having a length $\frac{1}{2}\delta_2$, would be placed under the original leaf. The prevailing theory advises that the resulting spring of Fig. 3 will support, with equal safety and equal deflection, a load of double that of our original one-leaf spring, or $2P$ if the load for the single leaf is P.

FIG. 3.



Again, the theory in common use to-day indicates that the spring to carry $3P$ must be made as shown in Fig. 4, where it will be seen that the second leaf has a length of $\frac{2}{3}l$ and the short leaf a length of $\frac{1}{3}l$. In general, this theory assumes that "the number of leaves is directly proportional to the load." It should be noted that the "steps" or "overhangs" are all equal.

FIG. 4



For the present we are considering only springs composed of leaves of the same cross-section; later on we shall discuss the effect of varying the sections, or "grading" the springs.

Now, suppose that we consider a spring such as that shown in Fig. 4, and ask if the stresses are the same in all of the leaves, and if the maximum stress in each leaf is the same as that in the simple leaf of Fig. 1. The answer given by those who expound the ordinary theory is about as follows:

They say (in the case of Fig. 3) that, since the load is doubled, so is the maximum bending moment, the length being the same, and as the section modulus is also doubled, the stress is $\frac{2Pl}{2Z} = \frac{Pl}{Z}$ the same as before. Likewise at the point $\frac{l}{2}$ the bending moment is $\frac{2Pl}{2} = Pl$, so the stress there is the same as at the point of fixation. An exactly similar line of reasoning is applied to Fig. 4, and so on for any number of plates.

If we accept these statements as true—and the deductions are correctly made from the original assumption of the theory—then we must expect, *a priori*, that in any such spring each and every plate is liable to the same mathematical probability of concomitant failure.

How far is this concept verified by experiment? This is the crucial test to which all mechanical theories must submit; and any failure of a theory to explain the test results in a satisfactory manner is a proof of its inadequacy. The experimental verification of the theories of leaf springs was made possible by the endurance testing machine.

Imagine that we have constructed springs of, say, 2, 3, 4, . . . , etc., plates, the master leaf[4] being the same length in each spring, and all the leaves having the same cross-section; also that we put these springs into a vibratory testing machine, making each deflect the same distance *d*. What will happen? Since we have conducted exactly such a series of tests, we are able to give a definite reply to this question.

We tested 33 springs containing 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13 plates. All these springs were carefully constructed so as to reduce accidental errors to a minimum. The results of these tests were most astonishing; in each case (except two only) only one leaf in each spring broke and the broken leaf was always the shortest one! Why? In accordance with the usual theory, all the leaves composing the spring—or at least several of them—should have broken at one and the same time, and the liability of each leaf to fracture should be exactly the same, so that with our

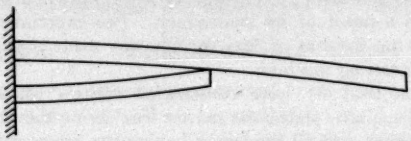
[4] The longest leaf of a spring, usually having eyes rolled or forged at the ends, is technically called the "master leaf," "main leaf," or "back."

considerable number of tests we should have had broken leaves in many positions in the springs. Why this enormous deviation from the results predicted by the theory? We must add another observation of great importance: in no two cases were the number of vibrations required to break the short leaf the same; on the contrary, *the number of vibrations required to break the short leaf decreased as the number of leaves in the spring increased!*

Here we have the results of careful experimental work which seemed to indicate the reverse of the theoretical prediction—a theory which has not been questioned since it was first proposed, probably in 1852—66 years ago! Various explanations were offered to account for the results, and among them the one which appeared to be the most logical and reasonable follows.

Consider, for simplicity, a two-leaf spring such as that shown in Fig. 3, and suppose it to be so constructed that when it is

FIG. 5.



not loaded, or, as we prefer to term it, "free," it is perfectly flat (if arched when free, it does not materially change the reasoning). Now, it is well known to engineers that in the making of a spring each leaf is given a different radius of curvature, as shown roughly by Fig. 5. When the leaves are clamped together by the centre bolt, note that the leaves are deflected in opposite directions; the master leaf is deflected upward at the ends, or in the opposite direction to the deflection caused by the external load, while the short leaf is deflected downward, or in the same direction as the deflection caused by the external load. As a consequence, it follows that the short leaf of a spring, no matter what the number of leaves, is thereby *already loaded positively*. Similarly, the upper leaf is *unloaded* or loaded negatively. These initial loading and unloading effects produced by the method of manufacture are present in all commercial leaf springs, though in different degrees.

This method of building leaf springs with initial deflections of the separate lamina, technically called "nip," helps the old theory to explain the breaking of the short leaf first. For it is argued, and reasonably, that, since the short leaf is already positively stressed by the nipping load, this stress must be added to that produced by the external load, with the result that the short leaf has the greatest stress in it, and will therefore be the first to break. This appears to be a fair explanation of one of the facts brought to view by the destruction tests; but when put to a further test, however, the explanation fails utterly.

We built approximately the same number and the same kind of springs as those mentioned previously, but having one important difference: all of these series of springs were built with leaves that were practically "nipless"; in other words, the leaves were so curved that when laid one against the other, without any pressure being applied, the adjacent leaves touched practically everywhere along their entire length, or they were (in shop parlance) "dead." There were, therefore, no initial flexural stresses in these springs.

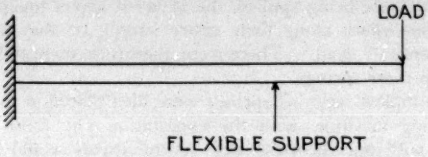
These nipless series of springs were then placed in the endurance testing machine, with the expectation (by those not acquainted with our theories) that several leaves would break at once, and that the fractures would occur in various positions in the springs. What we did obtain was a surprise! All the nipless springs broke the short leaf first, just the same as before!—although one very noticeable difference was found; namely, that the number of vibrations required to cause fracture was increased. This latter result might, of course, have been anticipated *a priori*, but that the short leaf should continue to break first, and with such repeated insistence, was a great surprise to those who were not acquainted with the new theories which the present paper expounds.

Many other experiments were made, but one only is of interest here. In a series of springs, all the leaves above the shortest were made of plain carbon spring steel; the shortest leaves alone were made of high-grade alloy-steels (silico-manganese and chrome-vanadium were used in alternate tests). The endurance results showed that, while the number of vibrations required to cause breakage was somewhat increased, the short leaf persistently continued to fail first.

These facts, constantly shown by the endurance testing machine, and so often confirmed from observation of leaf springs in practice, together with the fact that it has been found necessary in railway as well as in automobile practice to adopt a "constant" in the ordinary formula for the strength of leaf springs which allows for a very nominal working stress, all indicated the necessity for a new analysis, of quite a different character from that of the academic texts. It is this new analysis, the result of several years of investigation, and of continued experimental work and practical application, which we now publish for the first time.

The new theory has one important element in its favor—it explains exactly everything that has needed an explanation; analyzes fully and completely the minute details of the behavior

FIG. 6.



of each leaf and the stress at every point in the leaves; predicts with certainty the endurance of each leaf comprised in a spring. It has explained, easily and consistently, each and every one of the numerous apparent inconsistencies shown by the many tests which have been made, and also the results found "on the road." It has enabled us to build springs having a far greater endurance than those designed on the basis of the old theory, and experience indicates that we can expect to obtain even better results in the near future.

THE NEW THEORY OF LEAF SPRINGS.

If a series of laminæ having the form of a cantilever, and having equal widths and equal or different thicknesses, be assembled so as to form a leaf spring, and such spring be loaded in the usual manner, it will be found that each leaf touches the one above it only at the point of encastrèment and its extremity. This may readily be shown theoretically, and is obvious in practice, as will be admitted by all who have examined the wear on

spring leaves which have been in use for some time—it being understood that leaves with ordinary non-tapered ends are here being considered, and not the special cases to be considered later of the tapered leaf spring. The relations given in this exposition refer primarily to "square point" leaves; we have made elaborate investigations of the effects of tapered points, but these are to be treated in another paper; the present paper is intended to deal mainly with the fundamental relations.

Any leaf of a spring except the short plate may be considered as a beam, encastrè at one end, loaded at the other, and having a flexible support somewhere between the point of encastrèment and that of application of the load, and this is the fundamental assumption on which our new theory of leaf springs is based. This fundamental principle is illustrated by Fig. 6; its adoption leads to many special and interesting relations, a few of which we will proceed to develop.

Let l = the half length of the short leaf for a semi-elliptic spring, or the length for a cantilever spring; l_2 that for the second leaf, etc., so that l_n is the length for the nth leaf;

M = the bending moment at any section;

I_n = the moment of inertia of the section of the nth leaf;

E = the modulus of direct elasticity of the material;

W_n = the reaction, or pressure, between the end of the nth leaf and the $n+1$th leaf;

x = the distance of any section under consideration from the point of encastrèment;

y = the deflection at any point; and

δ_n = the deflection at the end of the nth leaf, where W_n acts.

The fundamental relation between the curvature (in ordinary cases) and the bending moment is well known to be:

$$EI\frac{d^2y}{dx^2} = M \qquad (1)$$

Now, referring to Fig. 7, it will be seen that for the $n+l$th plate, we must have; for

$$o \ll x \ll l_n$$

$$M = EI_{n+1}\frac{d^2y}{dx^2} = W_{n+1}(l_{n+1}-x) - W_n(l_n-x) \qquad (2)$$

and for

$$l_n \ll x \ll l_{n+1}$$

$$M = EI_{n+1}\frac{d^2y}{dx^2} = W_{n+1}(l_{n+1}-x) \qquad (2a)$$

Integrating, and noting that $EI_{n+1}\frac{dy}{dx}$ from (2) must be equal to $EI_{n+1}\frac{dy}{dx}$ from (2a) when x has the value l_n, we obtain: for

$$0 \leqslant x \leqslant l_n$$

$$EI_{n+1}\frac{dy}{dx} = W_{n+1}\left(l_{n+1}-\frac{x^2}{2}\right)W-_n\left(l_n x-\frac{x^2}{2}\right) \quad \ldots\ldots(3)$$

and for

$$l_n \leqslant x \leqslant l_{n+1}$$

$$EI_{n+1}\frac{dy}{dx} = W_{n+1}\left(l_{n+1}-\frac{x^2}{2}\right)-W_n\frac{l_n^2}{2} \quad \ldots\ldots(3)$$

Integrating again, and noting the equality of $EI_{n+1}\,y$ from (3) and (3a) for $x=l_n$, we obtain for

$$0 \leqslant x \leqslant ln$$

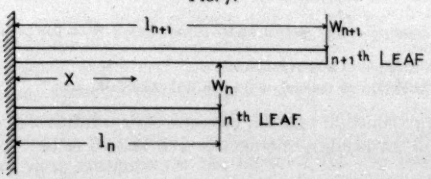
$$EI_{n+1}y = W_{n+1}\left(\frac{l_{n+1}x^2}{2}-\frac{x^3}{6}\right)-W_n\left(\frac{l_n x^2}{2}-\frac{x^3}{6}\right) \quad \ldots\ldots(4)$$

and for

$$l_n = x = l_{n+1}$$

$$EI_{n+1}y = W_{n+1}\left(\frac{l_{n+1}x^2}{2}-\frac{x^3}{6}\right)-W_n\left(\frac{P_n x}{2}-\frac{P_n}{6}\right) \quad \ldots\ldots(4a)$$

FIG. 7.



Putting $x=l_n$ in (4) and $x=l_{n+1}$ in (4a) we obtain:

$$EI_{n+1}\delta_n = W_{n+1}\left(\frac{l_{n+1}l_n^2}{2}-\frac{l_n^3}{6}\right)-W_n\frac{l_n^3}{3} \quad \ldots\ldots(5)$$

$$_{n+1}\delta_{n+1} = W_{n+1}\frac{P_{n+1}}{3}-W_n\left(\frac{P_n l_{n+1}}{2}-\frac{P_n}{6}\right) \quad \ldots\ldots(5a)$$

Now putting n for $n+1$ in (5a) there results:

$$EI_n\delta_n = W_n\frac{P_n}{3}-W_{n-1}\left(\frac{P_{n-1}l_n}{2}-\frac{P_{n-1}}{6}\right) \quad \ldots\ldots(6)$$

And equating the values of δ_n as given by (5) and (6) we obtain (we assume the material of all the leaves to be the same, so that the E's are equal):

$$6E\delta_n = \frac{W_{n+1}(3P_n l_{n+1}-P_n)-2W_n l_n^3}{I_{n+1}} = \frac{2W_n l_n^3-W_{n-1}(3l_n^2{}_{-1}l_n-P_{n-1})}{I_n} \quad \ldots(7)$$

If the material of the leaves be different, then equation (7) becomes:

$$6\delta_n = \frac{W_{n+1}(3l_n^2 l_{n+1} - l_n^3) - 2W_n l_n^3}{E_{n+1} I_{n+1}} = \frac{2W_n l_n^3 - W_{n-1}(3l_n^2 - 1l_n - 1l_n^3 - 1)}{E_n I_n} \quad \ldots\ldots (7a)$$

Equation (7a) is only of academic interest, for clearly the material of all the leaves in any spring is always the same; still we wish to indicate the generalization of the theory. The reader may find interest in working out a composite spring in which the leaves are composed of materials having various values of E.

Equation (7) is the most important and fundamental relation between the lengths of the leaves and their corresponding reactions or tip pressures, W. For any particular spring of given dimensions, the reactions may readily be determined in progressive order, starting with the bottom or short leaf.

For the short leaf we have $n = 1$, and $l_0 = 0$, so that the relation between the short leaf and the second one is:

$$\frac{W_2(3l_1 l_2 - l_1^3) - 2W_1 l_1^3}{I_2} = \frac{2W_1 l_1^3}{I_1}$$

and since the l's are usually given, the W's are determined from this relation. Knowing the loads and the lengths, as well as the cross-sections, the stresses are then readily found.

Equation (7) explains the many difficulties and inconsistencies found when endeavoring to force the old theory into agreement with practice; it shows at once that the strength of a spring is not nearly in direct proportion to the number of plates. It interprets, without any modification, the reason for the failure of the short leaf of any ungraded spring, and of nearly all the graded ones; it shows the reason why the endurance at a given deflection decreases with the increase in the number of leaves, and it fully explains many apparent inconsistencies which we have met with on the endurance testing machine, and the results of practice.

Having now shown the derivation of one of our fundamental formulæ, we propose to show its application to the study of particular cases. Not the least of its usefulness will be found in its application to the study of the exact character of the deflection experienced by each leaf of a spring. We shall show further that equation (7) explains fully all the difficulties indicated by the endurance tests mentioned previously, and also

many others for which the old theory is unable to offer any rational explanation.

We may mention here that the fundamental reason for failure of the old theory is that it ignores the clamping of the leaves at the centre of a semi-elliptic spring, or at the end of a cantilever spring. The old theory assumes each plate can move vertically and independently at the point of encastrèment, and it is quite correct if such a condition holds; this condition never does hold in practice, and the effect of the clamping is sufficient to vitiate the old theory to such an extent as to render it useless from both the theoretical and practical points of view.

We will now apply our established equations to see what they may reveal; we will also test them to discover if they are capable of explaining the facts revealed by the endurance tests mentioned in the earlier portion of this paper.

As the simplest elementary case let us apply the fundamental equation (7) to a two-leaf spring. We will take the overhangs equal, so as to get an exact comparison with the results of the old theory as outlined above.

If the plates are of the same cross-section, the moments of inertia are equal, then the fundamental equation becomes:

$$W_{n+1}(3l_{n+1}^2 - l_n^2) - 2W_n l_n^3 = 2W_n l_n^3 - W_{n-1}(2l_n^3 - 1l_n - l_n^3 - 1)$$

or for the present case, where $n = 1$ and $l_2 = 2l_1$, we have:

$$W_2(3l_2^2 l_2 - l_1^3) - 2W_1 l_1^3 = 2W_1 l_1^3 - W_0(3l_1^2 l_1 - l_0^3)$$

and as $l_0 = 0$ (has no existence), the last term vanishes, and l_1 cancels, leaving:

$$5W_2 - 2W_1 = 2W_1,$$

or

$$W_2 = \tfrac{4}{5} W_1$$

Here we see that the new theory indicates the reactions are not at all equal. To put it into words, our theory shows that for a unit load W to act on the point of the short leaf, the load applied to, or the pressure required on the end of the next longer leaf, is only 4/5 of the unit load W_1; or, for unit load placed on the end of the second leaf (in the present case the master leaf, there is produced a reaction or pressure on the end of the short leaf equal to 5/4 times the unit load. This is a very different result from that given by the old theory, and shows that

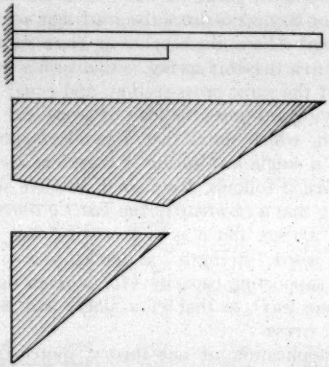
the actual stress in the short leaf is 25 per cent. more than is accorded to it by the old theory.

The maximum bending moment on the short leaf is $W_1 l_1$; that on the plate next above it is

$$W_2(l_2-l_1) = W_2(2l_1-l_1) = W_2 l_1 = \tfrac{4}{5} W_1 l_1.$$

This calculation shows conclusively that the stress in the master leaf of a two-leaf spring, at its maximum value, can be only four-fifths of that in the short leaf. We see thus that the actual stress in the short leaf, according to our theory, is considerably the greater, which therefore accounts exactly for

Fig. 8.



the results our experiments persisted in showing and which is so frequently observed in practice; namely, that the short leaf fails first.

Fig. 8 shows clearly, in graphic form, the stress at every section of both plates; it will be noticed that the stress in the short lamina increases from zero at the end to a maximum at the point of fixation, while at the same time the stress in the master leaf increases from zero at the end to a maximum, which maximum occurs directly over the end of the short leaf, and then gradually *decreases* towards the point of fixation. The maximum stress in the master leaf is thus only four-fifths of that in the short leaf, and the stress in the master leaf at the point of fixture is only three-fifths of that in the short leaf at

the same place. It should be noticed, too, that the distribution of the stress is entirely different for the two leaves—a condition not even suspected heretofore.

Our next point is of still greater interest: it deals with the practical issue of the permissible loads which any spring may safely carry according to this new theory.

Since the short leaf of the two-leaf spring just considered is but one-half of the length of a single-leaf spring, the actual load W_1 which may be placed upon it is evidently equal to $2W_1$ (since for the same stress the load varies inversely as the length); hence, to produce double the pressure or reaction on the end of the short leaf we must place, on the end of the main leaf, 4/5 of the double, or $8/5 = 1.6$ times the load that we can put on a single-leaf spring! Hence the conclusion, from the application of this new theory to a two-leaf spring, is that such a two-leaf spring having plates of the same cross-section, and equal steps, is only capable of carrying 1.6 times the load of a one-leaf spring. The old theory, then, which states that a two-leaf spring is double the strength of a single leaf spring is therefore seen to be quite incorrect. Hence it follows, from what we have shown, we are correct in saying that *a two-leaf spring has 1.6 times the strength of a single-leaf spring*, and it is in this sense that we shall continue to use the word "strength" as applied to a spring; namely, the ratio of its supporting capacity (for a given maximum fibre stress in any one leaf) to that of a single leaf with the same maximum fibre stress.

A further application of our theory, quite similar to that just given, shows that a three-leaf spring has not a strength of 3, but only of 2.207; a four-leaf spring has a strength of 2.817, and a ten-leaf spring only 6.503. A twenty-leaf spring has a strength of but 12.689, instead of 20, as given by the old theory, the reduction of strength being therefore almost 40 per cent. These figures show very definitely the cause of failure from overloading springs designed on the assumption that the strength of such leaf springs varies in direct proportion with the number of leaves; it also shows why, when using the old formulæ, it has been found necessary in practice to adopt a "coefficient" allowing for an abnormally low apparent stress as mentioned above; the fact being, of course, that the actual stress is very much higher—a condition our theory shows rationally.

In practice it may be observed that for springs having a considerable number of plates there is, in addition to the master leaf, one or even several leaves having the same length as the master leaf; these leaves are called "full-length leaves." Our fundamental equation (7) deals readily with these cases, for any number of full-length leaves are exactly equivalent to a single leaf with a moment of inertia equal to the sum of the moments of such full-length leaves, and the fundamental equation allows for any relation between the moments of inertia of the various leaves.

To avoid tedious calculation of the reactions in each case, we have calculated the values of the reactions, as well as the strengths, for springs having up to as many as 20 leaves with one full-length leaf, and up to 25 leaves with 6 full-length leaves; these calculations are summarized in Tables I and II. In both of

TABLE I.

Reactions.

EQUAL SPACING.

K	$p=1$	$p=2$	$p=3$	$p=4$	$p=5$	$p=6$
1	1.0000	2.0000	3.0000	4.0000	5.0000	6.0000
2	.8000	1.2000	1.6000	2.0000	2.4000	2.8000
3	.7357	1.0144	1.2931	1.5718	1.8505	2.1292
4	.7044	.9184	1.1324	1.3464	1.5604	1.7744
5	.6860	.8598	1.0336	1.2074	1.3812	1.5550
6	.6740	.8203	.9666	1.1129	1.2592	1.4055
7	.6655	.7918	.9181	1.0044	1.1707	1.2970
8	.6591	.7702	.8813	.9924	1.1035	1.2146
9	.6542	.7534	.8526	.9519	1.0511	1.1503
10	.6503	.7399	.8295	.9191	1.0087	1.0983
11	.6471	.7287	.8104	.8920	.9737	1.0553
12	.6445	.7195	.7945	.8695	.9445	1.0195
13	.6423	.7117	.7811	.8504	.9198	.9892
14	.6404	.7050	.7696	.8341	.8987	.9633
15	.6388	.6992	.7596	.8200	.8804	.9408
16	.6375	.6943	.7510	.8078	.8645	.9313
17	.6365	.6900	.7435	.7971	.8506	.9042
18	.6356	.6863	.7369	.7876	.8383	.8890
19	.6350	.6831	.7312	.7793	.8274	.8756
20	.6344	.6802	.7260	.7718	.8176	.8634

these tables p is the number of full-length leaves in the spring, including the master leaf, k is the number of steps in the spring, and n is the total number of leaves, so that $n = k + p - 1$. Knowing the reactions, which are given in Table I, the strengths given by Table II are easily determined.

TABLE II.

Strength of Springs.

EQUAL SPACING.

K	$p=1$	$p=2$	$p=3$	$p=4$	$p=5$	$p=6$
1	1.000	2.000	3.000	4.000	5.000	6.000
2	1.600	2.400	3.200	4.000	4.800	5.600
3	2.207	3.043	3.879	4.715	5.551	6.387
4	2.818	3.674	4.530	5.386	6.242	7.098
5	3.430	4.299	5.168	6.037	6.906	7.775
6	4.044	4.922	5.800	6.678	7.556	8.434
7	4.658	5.542	6.426	7.310	8.194	9.078
8	5.273	6.162	7.051	7.940	8.829	9.718
9	5.888	6.781	7.674	8.567	9.460	10.353
10	6.503	7.399	8.295	9.191	10.087	10.983
11	7.118	8.016	8.914	9.812	10.710	11.608
12	7.734	8.634	9.534	10.434	11.334	12.234
13	8.350	9.252	10.154	11.056	11.958	12.860
14	8.966	9.870	10.774	11.678	12.582	13.486
15	9.582	10.488	11.394	12.300	13.206	14.112
16	10.200	11.108	12.016	12.924	13.832	14.740
17	10.820	11.730	12.640	13.550	14.460	15.370
18	11.441	12.353	13.265	14.177	15.089	16.001
19	12.055	12.969	13.883	14.797	15.711	16.625
20	12.688	13.604	14.520	15.436	16.352	17.268

A study of Table II of the relative strengths of leaf springs will reveal a very interesting point which is brought to light by the present theory; namely, that to carry too many full-length leaves in a spring is a decided disadvantage. Thus a two-leaf spring is seen to have a strength of 1.6 and a three-leaf spring a strength of 2.207, while a three-leaf spring with $p = 2$ has a strength of 2.4, and with $p = 3$, or all the leaves full-length, a strength of 3, as might be expected *a priori*. A four-leaf spring with $p = 1$ has a strength of 2.818, and with $p = 2$ it has a

strength of 3.043, which again agrees with expectation But now observe that a four-leaf spring with $p = 4$ has a strength of 4, while a five-leaf spring with $p = 4$ is no stronger; this seems strange. Then notice that a five-leaf spring with $p = 5$ has a strength of 5, while a six-leaf spring with $p = 5$ has a strength of only 4.8; the addition of a short leaf has thus actually weakened the spring. Of course, such designs are outside of working experience, but the point is of considerable interest, as it shows that where there are several plates of the same length the addition of a shorter plate may actually weaken the spring. This is a condition which the old theory would never have suspected. We see, therefore, that there are limits to the corrected empiric equations of Henderson or Morrison which they did not announce; the absence of the *rationelle* of the correct theory of leaf springs naturally accounts for their not stating the limits in their expositions.

DEFLECTION OF SPRINGS.

The deflection of a spring has long been a favorite in engineering discussions as a means of verifying the old academic theory of the leaf spring. The practical deflection results having often been found to be in fair agreement with the academic predictions, they have frequently been urged as a confirmation of the theory (we may here mention that our theory shows that in general the deflection errors of the old theory are much less than the stress errors). The many discrepancies which did occur were explained by a series of carefully phrased objections which apparently answered the purpose up to the present time. Thus we find that if the calculated deflection was smaller than that found on a test, it was easily explained as due to the friction of the leaves, or "modulus variation" of the steel, etc. As a matter of fact, carefully conducted tests showed that none of the factors mentioned could explain the large differences often found between the "theoretical" and the "practical" deflections. The failure of the old theory is due to its real and inherent deflects, and not to any imaginary variations of the material, etc. Thus, for example, the old theory supposed that the reactions are equal, which we have shown to be very far from the fact; it necessarily follows, therefore, that there must be analogous errors in the assumption for the deflection formulæ.

The old theory shows, for example, that the deflection of a two-leaf spring under a load of $2W$ is the same as that of a single-leaf spring under a load of W. Indeed, the old theory says that the deflection is inversely proportional to the number of leaves in the spring (supposing all to be of the same cross-section), or that it is inversely proportional to EI at the centre of the spring. The old theory does not consider the effect produced by changes in the length of the steps; it does not, in fact, consider the effect of the stepping at all. The mere mention of this fact is sufficient to show that the old theory is inadequate; a very serious error may easily be committed by ignoring the effect of the stepping on the deflection of a spring, as may be gathered from our fundamental equation (7), which shows that the deflection depends on the length of each and every plate.

For springs having all the leaves of the same cross-section, the deflection may be expressed by a simple formula as follows: The fundamental relation of equation (7) becomes:

$$\delta_n = \frac{2W_n l_n^3 - W_{n-1}(3l_n^2 - 1l_n - l_{n-1}^2)}{6EI}$$

$$= \frac{W_n l_n^3}{EI}\left\{\frac{2 - \frac{W_{n-1}}{W_n}\left[3\left(\frac{l_{n-1}}{l_n}\right)^2 - \left(\frac{l_{n-1}}{l_n}\right)^3\right]}{6}\right\}$$

which is of the form

$$\delta_n = \frac{CW_n l_n^3}{EI} \qquad (8)$$

where C represents the function in the brackets; we have calculated the values of C for many cases, and these are given in Table III. As an example, if l, E, and I are constant, the deflection will be directly proportional to CW, and we will take W to be unity for a single-leaf spring, so that $CW = 0.33333$. Then for a two-leaf spring W will be 1.6 from Table II, and C will be 0.20313 from Table III; so that $CW = 0.32401$, which is appreciably less than the 0.33333 for the single-leaf spring. For a ten-leaf spring we have $6.50 \times 0.04813 = 0.31299$, which is still less; the old theory says, however, that they would all be the same. At the same time, it will be noticed that the error of the deflection given by the old theory is much less than the error of the stress, as previously mentioned.

Now that we have established the fundamental relations,

TABLE III.

Deflection Coefficients.

EQUAL SPACING.

K	$p=1$	$p=2$	$p=3$	$p=4$	$p=5$	$p=6$
1	.3333	.1667	.1111	.0833	.0667	.0556
2	.2031	.1233	.0894	.0703	.0580	.0493
3	.1456	.0986	.0755	.0614	.0517	.0447
4	.1130	.0822	.0654	.0545	.0464	.0410
5	.0924	.0706	.0578	.0491	.0427	.0378
6	.0781	.0618	.0518	.0447	.0393	.0352
7	.0676	.0550	.0469	.0410	.0365	.0328
8	.0596	.0495	.0429	.0379	.0340	.0308
9	.0532	.0451	.0395	.0352	.0318	.0290
10	.0481	.0413	.0366	.0329	.0299	.0274
11	.0447	.0385	.0343	.0310	.0283	.0261
12	.0404	.0355	.0319	.0290	.0267	.0247
13	.0373	.0330	.0299	.0274	.0253	.0235
14	.0347	.0311	.0283	.0260	.0241	.0225
15	.0325	.0293	.0268	.0248	.0230	.0215
16	.0306	.0277	.0255	.0236	.0220	.0206
17	.0289	.0263	.0243	.0226	.0211	.0199
18	.0273	.0250	.0231	.0216	.0203	.0191
19	.0260	.0238	.0221	.0207	.0195	.0184
20	.0247	.0227	.0212	.0199	.0188	.0178

we propose to show other new relations of practical interest which our theory enables us to formulate.

We have seen that in the ordinary leaf spring with equal steps the reactions are not equal, and the stresses are not equal either. It may therefore occur to the reader that if it were possible to make the reactions equal we might also obtain equal stresses. The attempt would therefore be to question the effect produced by, say, for example, altering the steps, or changing the lengths of the leaves. To make the reactions equal in any spring is easily done by an application of the fundamental equation (7), which now becomes:

$$3l_n^2 l_{n+1} - l_n^3 - 2l_n^3 = 2l_n^3 - 3l_n^2 l_{n-1} + l_{n-1}^3$$

or

$$3l_n^2 l_{n+1} = 5l_n^3 - l_{n-1}^3 - l_n^2 l_{n-1}(3l_n - l_{n-1})$$

for, as the W's are now supposed to be equal, they naturally

cancel, and for the present we are considering only leaves of the same cross-section, so that the I's are also equal. For $n = 1$ this equation evidently becomes:

$$3l_1^2 l_2 = 5l_1^3 - l_0^2(3l_1 - l_0)$$

and the last term vanishes as before, since $l_0 = 0$, and on dividing by $l^3{}_1$, there results:

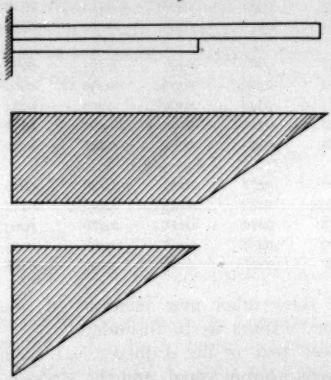
$$3l_2 = 5l_1$$

or

$$l_2 = \tfrac{5}{3} l_1$$

and this is the answer to the question proposed for the two-leaf spring. For further reference we may consider Fig. 9.

FIG. 9.



The maximum bending moment in the short leaf is Wl_1, and in the master leaf is $W(l_2 - l_1) = 2/3 Wl_1$. Now, since l_1 is three-fifths of l_2, the maximum bending moment on the short leaf is three-fifths of what it would be with a single-leaf spring, and, reciprocally, the strength of a two-leaf spring made to these proportions is $5/3 = 1\frac{2}{3}$ times that of a single-leaf spring, or $66\frac{2}{3}$ per cent. more, when the reactions were made equal. This is greater than the strength of an equally stepped spring, because the bottom leaf is longer. Indeed, the longer the bottom leaf (after a certain minimum), the greater the strength of the spring.

We have calculated out Tables IV, V, and VI, which show respectively the length of each plate necessary to secure equal reactions, the relative strengths of the various springs, and the deflection coefficients C for use in equation (8).

TABLE IV.

Overhangs.

EQUAL REACTIONS.

Plate No.	Overhang	Sum of overhangs = length of top plate
1	1.0000	1.0000
2	.6667	1.6666
3	.6312	2.2979
4	.6153	2.9132
5	.6061	3.5193
6	.6001	4.1194
7	.5958	4.7152
8	.5926	5.3078
9	.5901	5.8979
10	.5882	6.4861
11	.5866	7.0727
12	.5852	7.6579
13	.5841	8.2420
14	.5831	8.8251
15	.5822	9.4073
16	.5814	9.9887
17	.5807	10.5694
18	.5802	11.1496
19	.5797	11.7293
20	.5792	12.3085

The general laws which the preceding study enables us to formulate with regard to non-tapered leaf springs are:

1. In any leaf spring having leaves of equal cross-sections, and with equal steps, the reactions or pressures between the leaves continually decrease from the short leaf toward the master leaf, as do likewise the stresses.

2. In any leaf spring having leaves of equal cross-sections, and in which the reactions or pressures between the leaves are equal, the steps or overhangs continually decrease from the short leaf toward the master leaf.

In Fig. 9 we show graphically the result of making the reactions equal, and its effect on the stress distribution. The stresses are greatly altered, and are made uniform in the longer leaf for a distance of three-fifths of its length. This graphic

TABLE V.

Strength of Springs.

EQUAL REACTIONS.

K	$p=1$	$p=2$	$p=3$	$p=4$	$p=5$	$p=6$
1	1.000	2.000	3.000	4.000	5.000	6.000
2	1.667	2.500	3.333	4.166	4.999	5.832
3	2.298	3.310	3.962	4.794	5.626	6.458
4	2.913	3.748	4.583	5.418	6.253	7.088
5	3.519	4.356	5.193	6.030	6.867	7.704
6	4.119	4.958	5.797	6.636	7.475	8.314
7	4.715	5.556	6.397	7.238	8.079	8.920
8	5.308	6.151	6.994	7.837	8.680	9.523
9	5.898	6.742	7.586	8.430	9.274	10.118
10	6.486	7.331	8.176	9.021	9.866	10.711
11	7.073	7.918	8.763	9.608	10.453	11.298
12	7.658	8.504	9.350	10.196	11.042	11.888
13	8.242	9.088	9.934	10.780	11.626	12.472
14	8.825	9.672	10.519	11.366	12.213	13.060
15	9.407	10.254	11.101	11.948	12.795	13.642
16	9.989	10.837	11.685	12.533	13.381	14.229
17	10.569	11.417	12.265	13.113	13.961	14.809
18	11.150	11.998	12.846	13.694	14.542	15.390
19	11.729	12.578	13.427	14.276	15.125	15.974
20	12.308	13.157	14.006	14.855	15.704	16.555

analysis shows also why we can carry a greater safe load on this spring than on the spring with equal steps shown in Fig. 7, for we stress the main leaf more uniformly throughout its length, and so place a larger volume of metal at work; at the same time, the short leaf being longer, there is a greater total weight of metal in the spring, and actually the increase of strength is not in proportion to the extra weight of metal, for the increase of strength is only 4.1 per cent., while the increase of weight is 6.7 per cent.

TABLE VI.

Deflection Coefficients.

EQUAL REACTIONS.

K	p=1	p=2	p=3	p=4	p=5	p=6
1	.3333	.1667	.1111	.0833	.0667	.0556
2	.1893	.1187	.0871	.0689	.0571	.0487
3	.1339	.0935	.0726	.0594	.0504	.0428
4	.1041	.0776	.0625	.0525	.0453	.0399
5	.0853	.0665	.0551	.0465	.0412	.0367
6	.0723	.0582	.0493	.0428	.0379	.0340
7	.0628	.0519	.0446	.0393	.0351	.0317
8	.0566	.0468	.0408	.0363	.0327	.0297
9	.0499	.0427	.0376	.0337	.0306	.0280
10	.0452	.0392	.0349	.0315	.0288	.0265
11	.0414	.0363	.0326	.0296	.0272	.0251
12	.0381	.0337	.0308	.0279	.0257	.0239
13	.0354	.0315	.0287	.0264	.0244	.0227
14	.0330	.0297	.0271	.0250	.0233	.0217
15	.0309	.0279	.0257	.0238	.0222	.0208
16	.0291	.0264	.0244	.0227	.0212	.0198
17	.0274	.0251	.0232	.0217	.0203	.0192
18	.0260	.0239	.0222	.0208	.0195	.0184
19	.0247	.0228	.0212	.0199	.0188	.0178
20	.0235	.0217	.0204	.0192	.0181	.0172

Observe in Fig. 9 that the *stresses are still the greatest in the short leaf.* It is impossible to alter this by merely changing the steps.

Irrigation in Quincy Valley, Washington. ANON. (U. S. Geological Survey, *Press Bulletin*, No. 343, November, 1917.)—One of the most interesting experiments ever made in the reclamation of the arid West is at present in progress in Quincy Valley, Washington, where well water is being pumped from maximum depths of 300 feet to irrigate apple orchards, and where, at one of the largest plants, about 1000 gallons a minute is recovered by means of a huge reciprocating pump from a single well in which the water stands about 230 feet below the surface. In order to ascertain more definitely the quantity of ground water available for pumping in this

region, the United States Geological Survey, Department of the Interior, in response to requests and inquiries from many interested persons, recently investigated the ground-water conditions.

In 1916 about 4000 acres were irrigated in Quincy Valley, of which 3300 acres were supplied by water pumped from wells and 700 acres by water pumped from Moses Lake. The plants that pump water from wells have lifts ranging from 10 to 300 feet and capacities ranging from 25 to 1000 gallons a minute. With distillate costing 14 cents a gallon, the expense for fuel at 30 plants ranged from $1.50 to $18 per acre-foot of water pumped, the average being about $2 for an acre-foot lifted 50 feet. This cost could have been materially reduced by using distillate of lower grade.

Ground water for irrigation is obtained from three distinct formations—the basalt or lava beds, which supply water in the western part of the valley; the lake beds, which supply water in a belt extending through the central part of the valley, including the Morrison Flat; and the glacial-outwash deposits, which supply water in the eastern part of the valley, including the region adjacent to Crab Creek and Moses Lake.

The quantity of water in the basalt is large, and wells that yield several hundred gallons a minute obtain water from this formation. It is impossible to estimate closely the annual intake or the amount that can be recovered each year by pumping. There will no doubt be enough water to supply indefinitely the land now under irrigation, and experience may prove that considerably more land can be irrigated. However, the geologic and topographic conditions make it certain that the irrigation of the entire valley, or even of a large part of the area in which the wells end in basalt, is impossible. Moreover, these conditions indicate that it would be unwise at present to undertake irrigation projects aggregating more than a few thousand acres to be supplied from the water in the basalt.

Wells ending in the lake beds yield as much as 300 gallons a minute and furnish some water for irrigation. The water in the lake beds is derived from the same sources as that in the basalt and is not supplied to any important extent by Crab Creek or the glacial-outwash deposits.

It is estimated that the basalt, lake beds, glacial-outwash deposits, and Moses Lake will together afford enough water to irrigate each year as much as 15,000 acres in Quincy Valley. Experience may prove that the supply is adequate for a still larger acreage, but larger developments are not justified by the facts now available and must be regarded as unsafe. The most dependable supplies are those in the glacial-outwash deposits and in Moses Lake.

One of the features of the recent investigation was the accurate measurement of the depth to the water level in a large number of wells widely distributed throughout the valley. These measurements will make it possible in the future to determine the effects of pumping and to make more precise estimates of the ground-water supply.

SAG-TEMPERATURE CALCULATIONS OF TRANSMISSION LINES ON STEEP GRADES.*

BY

ALFRED STILL,
Purdue University, Lafayette, Indiana.

THE men engaged in the erection of overhead electric power transmission lines should be provided with tables or charts giving the sag or tension at different temperatures for a given length of span. This enables them to string the wires—either by sighting from pole to pole when erecting to the required sag, or by using a dynamometer when erecting to the required tension—so that the stress shall not exceed the specified limit under the weather conditions which will produce the assumed maximum loading.

If the storm conditions are such as to produce in the wire a stress n times as great as the stress when the wire hangs in still air at the same temperature under the influence of gravity only, there will be a reduction in length due to elastic contraction when this extra load is removed, and the maximum deflection from the straight line joining the points of support will now be less than under storm conditions. It should, however, be observed that, with a sufficient rise of temperature, the elongation of the wire will be such as to produce the same maximum deflection notwithstanding a reduction in the tension. This particular temperature —which may be called the "critical" temperature—is very easily calculated,[1] and since the relation between sag and tension is expressed by the well-known formula,

$$s = \frac{wl^2}{8P} \qquad (1)$$

it follows that, if s (the sag) and l (the span) remain constant, we obtain the relation

$$\frac{w}{P} = \frac{w}{P_e}$$

or

$$P_e = \frac{P}{n} \qquad (2)$$

* Communicated by the Author.

[1] This calculation, together with formulæ for use in obtaining sag-temperature curves, are given in the writer's book, "Overhead Electric Power Transmission."

where nw is the loading per foot of wire producing the maximum tension P, and w is the loading in pounds per foot which produces the tension P_e when the temperature is such that the sag of the conductor hanging in still air is the same as the maximum deflection under storm conditions.

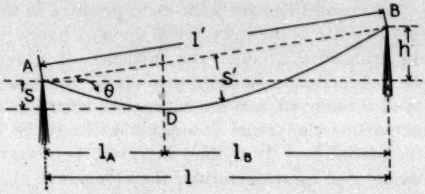
The sag at any other temperature will depend upon the length of the wire in the span, the connection between these quantities being given by the formula

$$\lambda = l + \frac{8s^2}{3l} \tag{3}$$

which is the approximate expression for the length of a parabolic arc.

When the points of support A and B (see Fig. 1) are not on

FIG. 1.



the same level, but are so nearly at the same elevation that the lowest point (D) of the span lies somewhere between the two points of support, the length of wire may be considered as the sum of two half spans of lengths l_A and l_B respectively: this leads to the formula

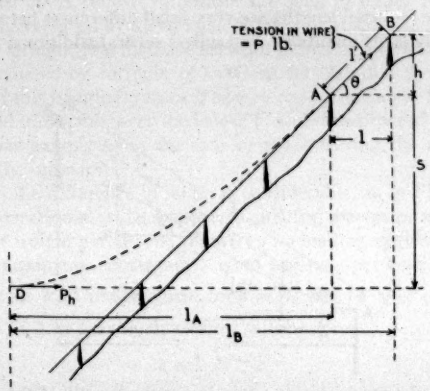
$$\lambda = l + \tfrac{8}{3}\left[\frac{(s+h)^2}{l-l_A} + \frac{s^2}{l_A}\right] \tag{4}$$

wherein the symbols correspond to the lettering of Fig. 1. By assuming different values of sag, s, the corresponding tension in the wire may be calculated by substituting $2l_A$ for l in formula (1), and the length of arc may be calculated by formula (4). Variations in the length of wire are due (*a*) to change of tension, (*b*) to change of temperature. The change in length due to cause (*a*) is known, because, for a given sag, the tension is known, and it follows that the change in temperature to produce such elongation or contraction as

is not accounted for by change of tension can easily be calculated. This outline of the method of obtaining data for the plotting of sag-temperature curves will suffice to show that small errors in calculating the length of the wire may lead to serious errors in the final results.

The horizontal distance l_A from the lower support A to the point D where the wire is horizontal (see Fig. 1) is readily calculated by considering that at the point D, where the horizontal component of the tension is P_h, the vertical component is zero;

FIG. 2.



while at a point half way between A and B the vertical component of the tension is $P_h \tan \theta$, or $P_h \times h/l$. This must be equal to the weight of a piece of wire of which the length is $\left(\frac{l}{2} - l_A\right)\frac{l'}{l}$ approximately. Thus

$$P_h \frac{h}{l} = w\left(\frac{l}{2} - l_A\right)\frac{l'}{l}$$

whence

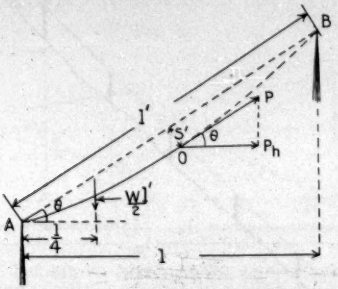
$$l_A = \frac{l}{2} - \frac{hP_h}{wl'} \qquad (5)$$

Consider now Fig. 2, where the span $A\,B$ is supposed to be on a steep incline. If the formula (5) is used for calculating the distance l_A from the lower support A to the point where the wire becomes horizontal, this quantity will be negative. It will determine the shape and position of an imaginary parabolic curve

as indicated by the dotted line of Fig. 2. The vertical component of the tension at the point B will be equal to the weight of the wire in the parabolic arc BD; while the vertical component at A will be the weight of the portion AD. The horizontal component (P_h) of the tension will be $P \cos \theta$, where P stands for the tension in the wire at the middle of the span AB.

Temperature-stress calculation can be made by considering the length of the wire in the span AB to be the difference between the imaginary half spans BD and AD, the procedure being exactly as indicated above. This method is, however, objectionable, because the required lengths are very small differences between comparatively large quantities, and unless several additional terms are

FIG. 3.



added to the approximate formula for the length of the parabolic curve, serious errors may be introduced.

The alternative method about to be explained makes use of what may be thought of as an equivalent horizontal span.

Fig. 3 is an enlarged view of the span AB of Fig. 2. The deflection s' at the centre of the span may be calculated by taking moments about the point A. The pull P in the direction AB, acting at a distance s', is balanced by the weight ($\frac{1}{2}wl'$) of the half span AO, acting vertically downward at an average distance $\frac{l}{4}$, whence

$$Ps' = \frac{wl'}{2} \times \frac{l}{4}$$

and

$$s' = \frac{wl^2}{8P\cos} \qquad (6)$$

The maximum deflection s' of the wire from the straight line AB joining the points of support is always small relatively to the distance $l' = AB$; and in computing the length of a curve which approximates to a straight line, no appreciable difference will be observable, whether the curve be considered as part of a parabola, or catenary, or ellipse, or circle. For our purpose, it will be most convenient to calculate the length of the wire by using formula (3), merely substituting s' for s, and l' for l.

The method of procedure here recommended for the calculation of sag-temperature or tension-temperature data can therefore be summed up as follows: Consider the span of either Fig. 1 or Fig. 3 to be replaced by an equivalent horizontal span of length l', being the straight line distance between points of support, and of sag s' calculated by formula (6). Consider also that the vertical loading of this imaginary span is now $w \cos \theta$ pounds per foot run, distributed uniformly over the length l', and then proceed with the calculations exactly as in the case of spans having the two supports on the same level.

When the difference in levels is considerable, as in Fig. 3, the proper correction must be made in calculating the factor n. Thus, if w is the weight per foot of the wire (ice loading neglected) and p is the maximum (horizontal) wind pressure per foot of wire, the resultant load under storm conditions will be $\sqrt{w^2 + p^2}$, and the value of n as previously defined will be

$$n = \frac{\sqrt{w^2 + p^2}}{w} \tag{7}$$

for horizontal spans. When the angle of slope, θ, becomes so large that $\cos \theta$ differs appreciably from unity, we must write

$$n = \frac{\sqrt{(w \cos \theta)^2 + p^2}}{w \cos \theta} \tag{8}$$

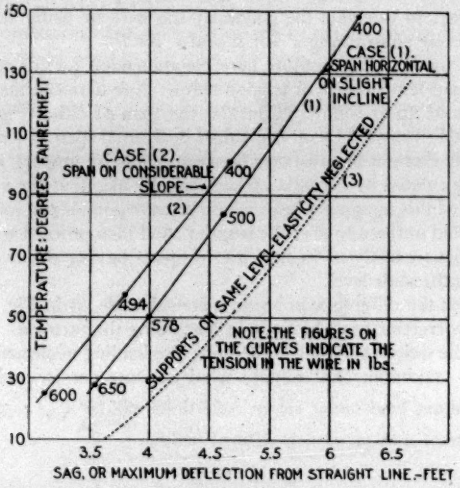
which is the value to be used in formula (2) when calculating the "critical" tension P_c from the assumed or specified permissible maximum tension P.

Space does not permit of the complete working out of a numerical example; but the results of some calculations on a practical line have been plotted in Fig. 4.

The assumptions as to distance between supports, maximum load, etc., are such as would be normal—even if unreasonable—in England, where the regulations governing factors of safety and

construction details are not such as to encourage the development of power transmission by overhead conductors. The reason for choosing data based on British rather than on American practice will be explained later.

FIG. 4.



Data for calculation of results given in Fig. 4:

Wire: No. 0 B. & S. solid copper. (This is almost exactly the same size as No. 0 S. W. G.)

Diameter of wire, $d = 0.325$ in.

Cross-sectional area of wire, $A = 0.083$ sq. in.

Weight of wire per foot, $w = 0.32$ lb.

Distance between supports measured horizontally, $l = 195$ ft.

Difference of elevation between points of support, $h = 140$ ft.

whence, Distance between supports measured on slope, $l' = 240$ ft.

Breaking stress (say) 55,000 lb. per sq. in.

Factor of safety = 5.

Maximum wind pressure = 15 lb. per sq. ft. of projected area of wire.

Temperature at which maximum wind pressure occurs, $t = 22°$ F.

The curve marked (2) in Fig. 4 gives the relation between temperature and deflection (s') which can be measured by sighting from pole to pole on the incline. The figures on the curve are the tensions corresponding to particular temperatures. Tensions for intermediate points can very quickly be calculated by means of formula (6) if it is desired to erect the conductors with a dynamometer rather than by measuring the dip.

The curve marked (1) refers to the same span placed horizontally; that is to say, with the points of support 240 feet apart on the same level. In both cases the specified limiting tension in the wire will be reached at a temperature of 22° F., with maximum wind-pressure in a direction perpendicular to the vertical plane passing through the points of support.

The dotted curve marked (3) in Fig. 4 is plotted from the same data as curve (1), except that the effect due to the elasticity of the wire has been neglected. The omission is often permissible, especially on long spans of aluminum wire; but on comparatively short spans of copper wire, as in the present instance, it is seen to give inaccurate results. The point has been referred to because of the peculiarity that in England—where the stringent regulations involving large factors of safety necessitate uneconomical construction with short spans—it is by no means uncommon to neglect the elasticity of the wire; while in America—where the longer spans are the cause of reduced stress variations—it is customary to take account of the changes in length due to variation of load.

Methods of Gas Warfare. S. J. M. AULD. (*Journal of the Washington Academy of Sciences*, vol. 8, No. 3, p. 45, February 4, 1918.)—Not so much is heard of gas warfare at the present time as two years ago, when the first use of that method of attack was made on the Western Front. Gas is, however, used to a tremendous extent, and the amount that has been and is being hurled back and forth in shells and clouds is almost unbelievable. The success of a cloud gas attack depends on thorough preparation beforehand. The attackers

must know the country, the layout of the trenches, and the direction and velocity of the wind with certainty. Favorable conditions are limited practically to wind velocities between twelve and fourteen miles per hour, with no upward currents. German gas attacks are made by two regiments of Pioneers, with highly technical officers, including engineers, meteorologists, and chemists.

The first attack was made with chlorine. If a gas attack is to be made with gas clouds, the number of gases available is limited. The gas must be easily compressible, easily made in large quantities, and should be considerably heavier than air. If to this is added the necessity of its being very toxic and of low chemical reactivity, the choice is practically reduced to two gases—chlorine and phosgene. The gas is contained in an ordinary cylinder like that used for oxygen or hydrogen. Pure chlorine did not satisfy quite all the requirements, as it is very active chemically and, therefore, easily absorbed. Pads soaked in solutions of sodium carbonate and thiosulphate were first used in the protective respirators. Later, with the introduction of phosgene, a gas which is very insidious and difficult to protect against sodium phenate was used.

There are so many conditions that have to be fulfilled in connection with the gas cloud that its use is limited. The case is different with gas shells. The gas shells are the most important of all methods of using gas on the Western Front, and are still in course of development. The first use of this method was with the celebrated "tear" shells. A concentration of one part in a million of some of these lachrymators makes the eyes water severely. The original tear shells contained almost pure xylyl bromide or benzyl bromide, made by brominating the higher fractions of coal-tar distillates. Another substance used in shells which simultaneously harasses and seriously injures is dichloro-diethylsulfide (mustard gas). It has no immediate effect on the eyes beyond a slight irritation. After several hours the eyes begin to swell and inflame and practically blister, causing intense pain, the nose discharges freely, and severe coughing and even vomiting ensue. The Germans have also used phenylcarbilamine chloride, a lachrymator, and diphenylchlorarsine, or "sneezing gas." The latter is mixed with high explosive shells or with other gas shells, or with shrapnel. It was intended to make a man sneeze so violently that he is unable to wear his mask. The sneezing gas has, however, not been a very great success.

Up to the present time there has been no material brought out on either side that can be depended upon to penetrate the respirator. The casualties are due to surprise or to lack of training in the use of masks. The mask must be put on and adjusted within six seconds, which requires a considerable amount of preliminary training if it is to be done under field conditions. Both sides are trying to find something the others have not used, and both are trying to find a "colorless, odorless, and invisible" gas that is highly poisonous. It is within the realm of possibility that the war will be finished literally in the chemical laboratory.

PHYSICS OF THE AIR.*

BY

W. J. HUMPHREYS,

Professor of Meteorological Physics, United States Weather Bureau.

CHAPTER XII.

EVAPORATION AND CONDENSATION.

INTRODUCTION.

THE presence of water vapor in the atmosphere is of such vital importance in the economy of Nature, and the source of so many phenomena, as to demand a study of, among other things: evaporation, by which the vapor is gotten into and rendered a portion of the atmosphere, mainly from free surfaces, but also from vegetation and damp soil; and condensation, by which in various forms it is removed from the air.

EVAPORATION.

Evaporation, the process by which a liquid becomes a vapor, or gas, is a result of the kinetic energy of the individual molecules. Some of the molecules at or near the surface have such velocities and directions that they escape from the liquid and thus become an integral part of the surrounding gas or atmosphere; and as the chance of escape, other things remaining equal, increases with the velocity, it follows (*a*) that the average kinetic energy of the escaping molecules is greater than that of the remaining ones, or that evaporation decreases the temperature of a liquid, and (*b*) that the rate of evaporation increases with increase of temperature.

Just as the kinetic energy of some of the molecules of the liquid carries them into the space about, so, too, the kinetic energy of some of the molecules of the gaseous phase causes them to penetrate into and thus become a part of the liquid. In reality, therefore, evaporation from and condensation onto the surface of a liquid, though necessarily taking place by discrete molecular units, practically are continuous processes whose ratio may have any value whatever. As popularly used, however, and even as

* Continued from page 372, vol. 185, March, 1918.

very commonly used scientifically, the term "evaporation" refers to the net loss of a liquid, and "condensation" to its net gain, so that, in this sense, both are said to be zero when, as a matter of fact, they are only equal to each other.

In the sense of net loss, which admits of accurate measurement, evaporation has been the subject of numerous investigations. Vegetation, soil, and the free water surface each offers its own peculiar and numerous evaporation problems. In what follows, however, only the free surface will be considered.

Evaporation into Still Air (a) from Tubes.—The rate of loss of a liquid by evaporation and diffusion, through a tube of fixed length and constant cross-section, into a still atmosphere has been carefully studied by Stefan.[68] Obviously, when a steady state has been attained, the rate at which the vapor escapes per unit area of the cross-section of the tube is constant, directly proportional to the driving force and inversely proportional to the resistance. These in turn are proportional, respectively, to the pressure gradient of the vapor along the tube and the partial pressure of the foreign gas at the same place. In symbols,

$$v = -\frac{k}{P-p}\frac{dp}{dn} = k\frac{d}{dn}\log(P-p),$$

in which v is the volume at 0° C. and 760 mm. pressure of the vapor that escapes per second per unit area of the cross-section of the tube, P the total pressure, a constant, $\frac{dp}{dn}$, the vapor pressure gradient along the tube at and normal to the cross-section at which the partial pressure due to the vapor is p, and k the coefficient of diffusion, whose value depends upon the nature of the vapor and the gas through which it is passing, and their temperature.

But as a steady state is assumed, it follows that both the rate of flow and the coefficient of diffusion k are independent of the distance n along the tube above the liquid surface. Hence,

$$V = \frac{kA}{h}\log\frac{P-p''}{P-p'}$$

in which V is the rate of total evaporation, A the area of the cross-section of the tube, h its height, or the distance of its top (tube supposed vertical) above the liquid, p'' and p' the partial pressures of the vapor at the free end and evaporating surface, respectively.

[68] *Sitzungsberichte der K. Akad. der Wis. Wien*, **68** (1873), 385–423.

All the terms in this equation except k may easily be measured, and thus k itself evaluated. But with k known, the rate of evaporation of the same liquid (water, say) from a circular tube or well of any given cross-section and length, provided the length is equal to or greater than the diameter, may be computed from the total gas pressure and the vapor pressures at the surface of the liquid and top of the tube.

Evaporation into Still Air. (b) from Flush Circular Areas.—The rate of evaporation into still air from a circular tank or pond filled flush with a relatively extensive plane which itself neither absorbs nor gives off any vapor has also been found by Stefan[69] susceptible of complete analysis.

From the general equation

$$v = -\frac{k}{P-p}\frac{dp}{dn}$$

it follows that

$$v = -k\frac{d}{dn}\log\frac{P-p_0}{P-p}$$

in which p_0 is the constant partial pressure of the vapor, during a steady state, at a given point. Hence if

$$u = \log\frac{P-p_0}{P-p}$$

$$v = -k\frac{du}{dn}$$

But this is identical with the flow of heat when $\frac{du}{dn}$ is the temperature gradient and k the thermal conductivity. Similarly it represents the flow of electricity, and also the field of force in the presence of a charged plate. If σ is the density of the surface charge on a plate, then

$$-\frac{du}{dn} = 4\pi\sigma.$$

Further, if E is the total charge,

$$E = Cu_1$$

in which C is the capacity of the plate and u_1 its potential. Hence the total diffusion, confined to *one* side, is given by the expression

$$V = 2\pi kCu_1$$

But

$$u_1 = \log\frac{P-p_0}{P-p_1}$$

[69] *Sitzungsberichte der K. Akad. der Wis. Wien*, 73 (1881), 943–954.

in which p_0 is the vapor pressure of the free air at a great distance from the evaporating surface and p_1 its pressure at the surface, or saturation pressure at the surface temperature.

The capacity of a circular disk of radius a is

$$C = \frac{2a}{\pi}$$

Hence

$$V = 4ak \log \frac{P - p_0}{P - p_1}$$

If p_0 and p_1 are both small in comparison to P,

$$V = 4ak \frac{(p_1 - p_0)}{P}, \text{ nearly.}$$

The real importance of this equation is its proof that evaporation, under the restricted conditions assumed, is proportional to the *diameter* (or other linear dimension) of the evaporating surface and *not*, as one might suppose, to its area. Obviously, therefore, evaporation in the open under ordinary conditions cannot be directly proportional, as often assumed, to the area involved.

Evaporation into Still Air (c) from Elliptical Areas.—Evaporation from an elliptical surface is slightly faster than from a circular one of equal area, but the difference is small until the major axis of the ellipse becomes several times longer than the minor; being only 1.11 as fast when the ratio of the axes is 1 to 4. Hence, when the axes do not greatly differ, a close approximation to the rate of evaporation from an elliptical surface is given by the equation

$$V = 4\sqrt{ab}\, k \log \frac{P - p_0}{P - p_1},$$

or, when p_0 and p_1 are small with reference to P,

$$V = 4\sqrt{ab}\, k \frac{p_1 - p_0}{P}$$

No exact mathematical expression has yet been obtained for the rate of evaporation into still air from surfaces of any other outline than the above—circle and ellipse—nor from either of these under outdoor conditions.

Evaporation in the Open.—Several hundred papers,[70] many of them giving the results of elaborate investigations, have been published on the evaporation of water from free surfaces, vege-

[70] Livingston, "An Annotated Bibliography of Evaporation," M. W. R., June, September, and November, 1908, and February, March, April, May, and June, 1909.

tation, and soil, and, while no equation has been found that expresses in terms of easily measurable quantities the rates of evaporation in the open, nevertheless several factors that control these rates have been discovered and more or less approximately evaluated. In the case of free, clean surfaces the principal factors are:

(a) *Salinity.*—It has repeatedly been observed that the evaporation of salt solutions decreases with increase of concentration, and that sea-water evaporates approximately 5 per cent. less rapidly than fresh water under the same conditions.

(b) *Dryness of the Air.*—Many observations have shown that, to at least a first approximation, the rate of evaporation is directly proportional, other things being equal, to the difference in temperature indicated by the wet and dry bulb thermometers of a whirled psychrometer.

According to the psychrometric formula developed by Apjohn, Maxwell, Stefan, and others,

$$p_1 - p_0 = AB(t_0 - t_1)$$

in which t_0 is the temperature and p_0 the vapor pressure of the free air, t_1 the temperature of the wet bulb (and surface of evaporating liquid), p_1 the saturation vapor pressure at temperature t_1, B the barometric pressure, and A a constant, provided ventilation is sufficient. But evaporation is proportional to the ratio of vapor pressure gradient to total pressure; that is,

$$V = k\frac{p_1 - p_0}{B}$$

Hence, other things being equal,

$$V = C\,(t_0 - t_1), \text{ approximately.}$$

But t_0–t_1 increases with the dryness, and hence so does evaporation.

(c) *Velocity of the Wind.*—All observers agree that evaporation increases with wind velocity, presumably through increase of the vapor pressure gradient, but the exact rate is not certain. At low velocities the effect is very great, while at 4 metres per second and considerably higher it appears to be roughly proportional to the velocity.

(d) *Barometric Pressure.*—Since the presence of any gas retards the diffusion of other gas molecules, whether of the same or different nature, it follows that when the vapor tension is comparatively small evaporation must vary inversely, nearly, as the total barometric pressure.

(e) *Area of Surface.*—Obviously the total amount of water evaporated must increase with the area of the evaporating surface, but not necessarily at the same rate. In fact, as already explained, if the evaporation is from a circular area into still air, it increases as the square root of the area. Under outdoor conditions, however, it is much more nearly, though probably by no means exactly, proportional to the total surface.

(f) *Temperature of the Water.*—Evaporation increases rapidly with the temperature of the water, roughly in proportion to the saturation pressure at that temperature, provided the general humidity of the air is low. When, however, the water surface is colder than the dew-point temperature of the air the evaporation becomes negative; that is, condensation obtains. When the air is colder than the water surface, evaporation may continue into it after saturation has been reached and thereby produce fog, the process being one of distillation and condensation.

Even when the water is frozen, it still continues slowly to evaporate (sublime) whenever the air is sufficiently dry, but the laws governing this sublimation are not well known.

Empirical Evaporation Equations.—Various equations, each at least partially empirical, have been devised to fit evaporation data obtained under special conditions. But the "constants" of these equations generally are not constant under other circumstances. Indeed, it may be that no simple equation of this kind, applicable to a wide range of conditions, is possible, and that therefore the most expeditious way to obtain useful evaporation data would be to note the daily, monthly, annual, etc., loss from standard exposures in each climatic region, and, wherever practical, to supplement such data by similar observations on lakes, ponds, and reservoirs. Controlled wind-tunnel experiments would also be interesting and useful.

One of the earliest experimenters to make a careful study of evaporation was John Dalton,[71] who says:

1. "Some fluids evaporate much more quickly than others."

2. "The quantity evaporated is in direct proportion to the surface exposed, all other circumstances alike."

3. "An increase of temperature in the liquid is attended with an increase of evaporation, not directly proportionable."

[71] *Mem. Manchester Lit. and Phil. Soc.*, 5, 574, read October, 1801.

4. "Evaporation is greater where there is a stream of air than where the air is stagnant."

5. "Evaporation from water is greater the less the humidity previously existing in the atmosphere, all other circumstances the same."

All these are important observations, but they do not fully justify the so-called Dalton equation which Dalton himself apparently never wrote.

Weilenmann and Stelling, working independently and at different places, obtained evaporation equations of the general form [72]

$$\frac{dn}{dt} = (cb + kw)(p_s - p_0)$$

in which c and k are constants, b the barometric pressure, w the wind velocity, p_s the saturation vapor pressure at the temperature of the water surface, and p_0 the actual vapor pressure in the free air at some distance from the water.

Fitzgerald [73] finds the rate of evaporation, E, in inches per hour, given approximately by the equation

$$E = \frac{(p_s - p_0)(1 + 1/2w)}{60}$$

in which p_s and p_0 have the meanings, respectively, given above, and w is the average wind velocity in miles per hour.

Various other equations have been found or proposed, but they either contain unevaluated functions or else were constructed to fit a special set of observations. The multiplicity of such equations, each of but limited use, emphasizes the difficulty of the evaporation problem, if not even the impossibility of finding for it a practical, universal equation.

CONDENSATION.

Condensation, the process by which a vapor is reduced to a liquid or solid, is induced by: (*a*) reduction of temperature, volume remaining constant; (*b*) reduction of volume, temperature remaining constant; (*c*) a combination of temperature and volume changes that jointly reduce the total vapor capacity. In the open, water vapor is condensed: (1) by contact cooling; (2) by the mixture of masses of air of unequal temperatures; (3) by expansional or dynamic cooling due to vertical convection, or,

[72] Hann, "Lehrbuch der Meteorologie," 3d edition, p. 214.

[73] *Trans. Amer. Soc. Civ. Eng.*, 15 (1886), 581–645.

occasionally, other causes, especially rotation, as in tornado and waterspout funnels.

Condensation Due to Contact Cooling.—During clear nights the surface of the earth, including vegetation and other objects, loses much heat by radiation, and thus both it and the air in contact with it are reduced to lower temperatures, obviously more pronounced the gentler the winds. After the dew-point has been reached all further loss of heat, producing now a much smaller proportionate decrease of temperature, results in the deposition, respectively, of dew and hoar-frost at temperatures above and below freezing. Similarly, relatively warm, moist air moving over a snow bank, for instance, may deposit some of its moisture.

In any typical case of surface cooling the deposition of dew, say, is caused partly by temperature reduction and partly by decrease of volume. Let the air, saturated at the absolute temperature T_0, be cooled, without change of volume, to T_1, and let the water vapor per unit saturated volume at these temperatures be w_0 and w_1, respectively. Then the quantity of water, $w_0 - w_1$, will be deposited per unit volume as a result of cooling alone, while if the pressure remains constant, as it does, approximately, the volume will be reduced in the proportion

$$\frac{V_0}{V_1} = \frac{T_0}{T_1}$$

and an additional quantity of water

$$w_1 \frac{T_0 - T_1}{T_0}$$

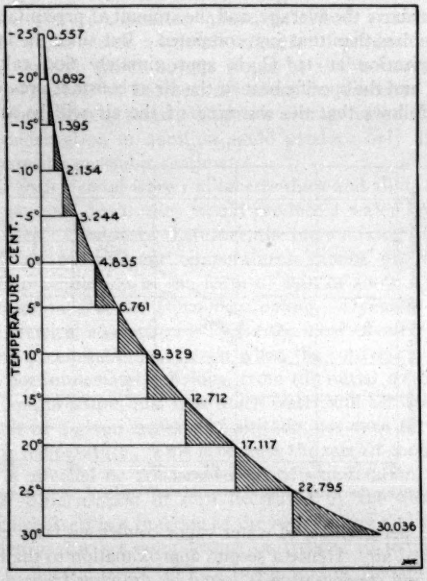
deposited per unit volume at temperature T_0. Hence the quantity q of water deposited per original unit volume due to both processes combined, decrease of temperature and decrease of volume, is given by the equation

$$q = w_0 - w_1 \frac{T_1}{T_0}$$

Condensation Due to Mixing.—Since the amount of water vapor per saturated unit volume decreases with temperature more rapidly than the absolute temperature itself, at least through the range of atmospheric temperatures (see Fig. 58), it follows that the mixture of two saturated masses of air of unequal temperatures must produce some precipitation. The amount of precipitation induced in this manner, however, is surprisingly small; indeed, it seldom can be sufficient to produce more than a light

cloud or fog. If the resulting temperature were the proportionate mean of the known temperatures of the quantities of air mixed, the amount of precipitation could easily be computed from the initial humidities. But the latent heat of the condensation prevents this simple relation from obtaining, so that the actual amount of precipitation can better be determined graphically than

FIG. 58.



Grammes of water vapor per saturated cubic metre, at different temperatures. Bases of shaded portions proportional to precipitations per 5° C. cooling from the temperatures indicated

by direct calculation.[74] To this end use a humidity temperature curve, such as Fig. 59, drawn to scale. For example, let equal masses of saturated air at 0° C. and 20° C. be mixed at normal pressure—certainly an extreme case. As a first approximation it may be assumed that the final temperature is 10° C., and, since there are 3.75, 7.52, and 14.34 grammes of water vapor per 1000

[74] Hann, "Lehrbuch der Meteorologie," 3d edition, p. 249.

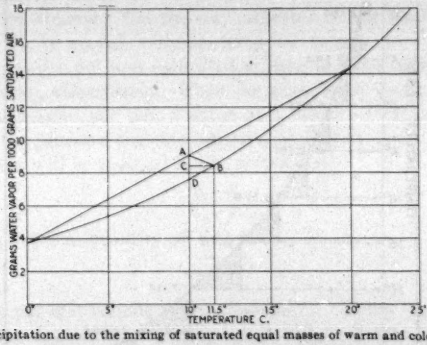
grammes of saturated air at normal pressure and 0° C., 10° C., and 20° C., respectively, the precipitation per 1000 grammes of the mixed air would seem to be

$$\frac{3.75+14.34}{2}-7.52=1.53 \text{ grammes},$$

represented by AD in the figure.

But the latent heat of condensation causes the final temperature to be above the average, and the amount of precipitated water, therefore, less than that just computed. But since the latent heat of vaporization at 10° C. is approximately 600 calories per gramme, and the specific heat of the air at constant pressure about 0.24, it follows that the warming of the air will be at the rate

FIG. 59.



Precipitation due to the mixing of saturated equal masses of warm and cold air.

of 2.5° C. per gramme of water vapor condensed from each 1000 grammes of air. Hence a second approximation to the final temperature and condensation is found by drawing from A a line in such direction that it shall indicate a change of 2.5° C. per gramme of condensate, and prolonging it until it meets the humidity temperature curve in B. This second approximation gives 11.5° C. very closely, instead of 10° C., as the temperature of the mixture, and 0.6 gramme, instead of 1.53 grammes, as the amount of condensation per 1000 grammes of air, a quantity which, as the figure shows, would be condensed by a temperature decrease of less than 1° C.

Obviously similar graphical solutions may easily be made for mixtures of unequal masses of air, for unsaturated air, for other pressures, and for other temperatures; though for temperatures slightly below 0° C. a greater latent heat of vaporization, approximately 680, must be used.

Since 1000 grammes of saturated air at 10° C. and normal pressure occupies very approximately $\frac{25}{31}$ of a cubic metre, it follows that the condensation above described is about 0.74 gramme per cubic metre, a quantity capable of producing only a light cloud through which objects would be visible to a distance of about 70 metres.[75] Further, assuming the diameter of each cloud particle to be 0.033 mm., Wagner's average value, it follows that the condensation in question could produce only about 39 such fog particles per cubic centimetre.

Even if such a cloud were 1 kilometre thick and all its droplets should be brought down, they would produce a water layer only 0.074 cm. deep. Obviously, therefore, the mere mixing of masses of humid air at different temperatures cannot produce any appreciable precipitation in the form of rain or snow.

Condensation Due to Dynamic Cooling.—Dynamic cooling incident to vertical convection is by far the most effective method of inducing precipitation, but even when the convection is adiabatic it is not immediately obvious, from the initial temperature, humidity, and pressure, just how much water will be precipitated as the result of a given increase of altitude, nor even for a given decrease of temperature. This is because the rate of cooling with elevation is affected by the latent heat of vaporization, and the amount of condensation in turn decreased by the increase of volume, which itself is a function of the temperature and pressure. The problem is further complicated, on passing to temperatures below 0° C., by the latent heat of fusion and by the abrupt considerable change in the heat of vaporization.

It therefore will be convenient to consider independently four possible stages in the dynamic cooling of a quantity of moist air: (*a*) the unsaturated; (*b*) the saturated at temperatures above 0° C.; (*c*) the freezing; and (*d*) the saturated at temperatures below 0° C.

This subject has been studied by several investigators, espe-

[75] Wagner, *Sitz. der K. Akad. der Wis. Wien.* 117 (1908), p. 1290.

cially Hann,[76] Guldberg and Mohn,[77] Hertz,[78] and Neuhoff.[79] Of these Neuhoff's paper appears to be the most explicit, and it therefore will be used as the basis of the following brief discussion.

Dry (Unsaturated) Stage.—Let the humidity be such that the mass ratio of dry air to water vapor is $1:w$. Then the number of calories, dQ, necessary to change the temperature of $1+w$ grammes of this atmosphere by dT and its volume by dV is given by the equation

$$dQ=(C_v+wC'_v)dT+Apdv,$$

in which C_v and C'_v are the specific heats at constant volume, respectively, of dry air and *unsaturated* water vapor, A the reciprocal of the mechanical equivalent of heat, and p the pressure.

But, for n grammes,

$$pV=nRT,$$

in which R is the well-known gas constant and T the absolute temperature, numerically, 273+ reading of centigrade thermometer. Hence,

$$dQ=(C_v+wC'_v)dT+(R+wR')AT\frac{dV}{V}$$

Since pressures in the open air are easily measured, while volumes are not, it will be more convenient to have this equation expressed in terms of the former. This may be done by substitutions from the equations

$$pdV+Vdp=RdT$$

and

$$C_v=C_p-AR$$

in which C_p is the specific heat at constant pressure.

If the convection is adiabatic—that is, if

$$dQ=0$$

[76] *Met. Zeit.*, 9 (1874), 321, 337.

[77] "Etudes sur les Mouvements de l'Atmosphère," part 1, Christiania, 1876, revised 1883; translation by Abbe, "Mechanics of the Earth's Atmosphere," Smithsonian Institution, 1910.

[78] *Met. Zeit.*, 1 (1884), p. 421; translation by Abbe, "Mechanics of the Earth's Atmosphere," Smithsonian Institution, 1891.

[79] *K. Prus. Meteor. Inst.*, 1 (1900), p. 271; translated by Abbe, "Mechanics of the Earth's Atmosphere," Smithsonian Institution, 1910.

these substitutions give the equation

$$(C_p+wC'_p)\frac{dT}{T}=A(R+wR')\frac{dp}{p},$$

or, by integration,

$$(C_p+wC'_p)\log\frac{T}{T_o}=A(R+wR')\log\frac{p}{p_o},$$

or, more simply,

$$\log\frac{p}{p_o}=K\log\frac{T}{T_o},\ K=\text{a constant},$$

in which p_o and T_o are, respectively, the initial surface pressure and temperature.

Obviously this equation is applicable only until saturation is attained.

Let e_o and e be, respectively, the initial and saturation vapor pressures corresponding to the total pressures p and p, and absolute temperatures T_o and T.

Then

$$\log\frac{e}{e_o}=K\log\frac{T}{T_o}$$

and

$$\log e-K\log T=\log e_o-K\log T_o=C,\ \text{a constant}.$$

If e_o and T_o are both known, C is also known, and since saturation vapor pressure depends upon temperature alone, and is known through a wide temperature range, it is obvious that both $\log e$ and $K\log T$ may be tabulated for many values of T, and that with such a table it is easy to pick out that value of T which gives the equation

$$\log e-K\log T=C,$$

the equation that determines the limit of the non-saturated or dry stage.

If the convection has been adiabatic it is obvious that the height h of the dry stage is given by the equation

$$h=100\ (T_o-T)\ \text{metres, approximately.}$$

It should be distinctly noted that in general vertical convection does not follow a fixed plumb-line. In cyclonic areas, for instance, the horizontal travel of the air doubtless often is hun-

dreds of times the vertical. Hence in the quadrant of such a region where the clouds are from lower latitudes the vertical temperature gradient at any given place is likely to indicate a greater departure from adiabatic expansion than actually has occurred. This, as explained, is because the proper p_o and T_o to use in the above equations are those that obtained when and where the mass of air in question started to rise, and not those at the surface beneath its position at the time for which the equations are given.

Under such circumstances the true values of p_o and T_o are not accurately known, but that does not affect the validity of the above discussion; it only emphasizes the complexity of the problem as frequently presented in Nature.

Rain (Saturated, Unfrozen) Stage.—After saturation has been attained any further convectional cooling leads to precipitation. It will be assumed that this water is carried along with the ascending current (never strictly true and less nearly so as the drops grow in size), thus leaving the process adiabatic and reversible, and that the volume of the liquid water is negligible in comparison to the space from which it was condensed.

Let p be the total pressure, made up of the two partial pressures, air pressure p' and saturated water vapor pressure e, a function of the temperature alone, and let the mass ratio of air to total water, condensed and uncondensed, be $1 : w$. Then

$$p = p' + e = \frac{RT}{V} + e.$$

As before, the quantity of heat necessary to change the temperature of 1 gramme of air by an amount dT and its volume by dV is

$$dQ' = (C_v dT + ART \frac{dV}{V}).$$

Let w' be the grammes of uncondensed water vapor per gramme of dry air. Then $w - w'$ is the corresponding number of grammes of liquid water. Hence the heat necessary to bring about the temperature change dT and the vapor change dw' is

$$dQ'' = w' s_2 dT + (w - w') s_1 dT + L dw'$$

in which s_2 is the specific heat of *saturated* water vapor (that is, its specific heat when the volume so changes with the temperature

as to maintain saturation and avoid condensation—a negative quantity), s_1 the specific heat of water, and L the latent heat of vaporization.

With T constant,

$$dQ'' = L\,dw' = Td\phi, \quad \text{or,} \quad \left(\frac{d\phi}{dw'}\right)_T = \frac{L}{T}, \ \phi \text{ being entropy.}$$

With w' constant,

$$dQ'' = w's_2dT + (w-w')\,s_1dT = Td\phi, \quad \text{or,} \quad \left(\frac{d\phi}{dT}\right)_{w'} = \frac{s_1(w-w') + s_2w'}{T}$$

But dQ is a perfect differential, therefore

$$\frac{d}{dw'}\left(\frac{s_1(w-w') + s_2w'}{T}\right) = \frac{d}{dT}\left(\frac{L}{T}\right)$$

and

$$(s_2 - s_1) = T\frac{d}{dT}\left(\frac{L}{T}\right)$$

Hence

$$dQ'' = ws_1dT + T\frac{d}{dT}\left(\frac{Lw'}{T}\right)dT,$$

and

$$dQ = \left(C_v dT + ART\frac{dV}{V}\right) + T\frac{d}{dT}\left(\frac{Lw'}{T}\right)dT + ws_1dT.$$

$$= \left(C_p dT - ART\frac{dp'}{p'}\right) + T\frac{d}{dT}\left(\frac{Lw'}{T}\right)dT + ws_1dT.$$

Hence, since the process is adiabatic,

$$(C_p + ws_1)\frac{dT}{T} + \frac{d}{dT}\left(\frac{Lw'}{T}\right)dT = AR\,\frac{dp'}{p'}.$$

By integration, using the subscript o for initial conditions,

$$\log\frac{p'}{p'_o} = \frac{C_p + ws_1}{AR}\log\frac{T}{T_o} + \frac{M}{AR}\left(\frac{Lw'}{T} - \frac{L_ow'_o}{T_o}\right)$$

in which M is the modulus of the system of logarithms used.

But

$$w' = \frac{Re}{R'p'}$$

Therefore

$$\log\frac{p'}{p'_o} = \frac{C_p + ws_1}{AR}\log\frac{T}{T_o} + \frac{M}{AR'}\left(\frac{eL}{p'T} - \frac{e_oL_o}{p'_oT_o}\right) = b\log\frac{T}{T_o} + \left(\frac{a}{p'} - \frac{a_o}{p'_o}\right).$$

in which b, a, and a_o obviously are determinable numerical quantities for given values of w, T, and T_o.

Hence

$$\log p' - \frac{a}{p'} - b \log T = \log p'_o - \frac{a_o}{p'_o} - b \log T_o = \text{a constant.}$$

From this equation a table may be constructed giving the relation between p' and T, and also, since e is known through a wide range of temperatures, between p and T. The value of w', or grammes of water per gramme of dry air, is given for any temperature by the equation,

$$w' = \frac{Re}{R'p'},$$

and the condensed water, w'', per gramme of dry air by the equation,

$$w'' = w - \frac{Re}{R'p'}.$$

Hail (Freezing) Stage.—Further lowering of the pressure beyond that at which the temperature reaches 0° C. causes, so long as there is any liquid water present, both freezing and evaporation. The latent heat of fusion keeps the temperature constant, while the increase of volume under the reduced pressure increases the vapor capacity and thus leads to evaporation.

To each gramme of dry air let there be w, w', and w'' grammes, respectively, of water, vapor, and ice. Then, as there is no change of temperature through this stage,

$$dQ = ART_o \frac{dV}{V} + Ldw' - Fdw''$$

in which F is the latent heat of fusion, and T_o the absolute temperature at 0° C. The negative sign is used because the heat of fusion is added, or becomes sensitive with freezing; that is, with decrease of pressure and increase of volume.

Assuming the process adiabatic, dividing by T, as before, and integrating, the above equation reduces to

$$\frac{AR}{M} \log \frac{V_1}{V_o} + \frac{L}{T_o}(w'_1 - w'_o) - \frac{F}{T_o}(w''_1 - w''_o) = 0.$$

Let the subscript o indicate the condition when the temperature reaches 0° C. with no ice, and subscript 1 the condition when all the water is just frozen. As the temperature is constant, e

will be the same at the beginning and end of the freezing process. At the end of the freezing $w''_1 = w - w'_1$.

Also,

$$\frac{V'}{V_o} = \frac{p'_o}{p'_1}; \; w'_o = \frac{R}{R'} \frac{e}{p_o - e}; \; w'_1 = \frac{R}{R'} \frac{e}{p_1 - e}; \text{ and } w''_o = o.$$

Hence

$$\log p'_1 - \frac{e}{p'_1} \frac{M(L+F)}{AR'T_o} = \log p'_o - \frac{e}{p'_o} \frac{M}{AR'} \frac{L}{T_o} - w \frac{M}{AR} \frac{F}{T_o}$$

This equation gives, in terms of known quantities, the relation between the partial pressures of the air at the beginning and end of the "hail stage," and therefore the depth of this stage, obviously determined by the amount of water to be frozen, which in turn depends on the original temperature and humidity.

Snow (Frozen) Stage.—At temperatures below o° C. there will be present in the air only ice and enough water vapor to produce saturation. Hence the discussion applicable to this stage is identical with that for the "rain stage," though two of the constants, specific heat and latent heat, will be different. The specific heat is now of ice, roughly one-half that of water, while the total latent heat is due to two distinct processes, fusion and vaporization. The equation, therefore, applicable to the snow stage is,

$$\log \frac{p'}{p'_o} = \frac{C_p + ws_i}{AR} \log \frac{T}{T_o} + \frac{M}{AR'} \left(\frac{e(L+F)}{p'T} - \frac{e_o(L_o+F_o)}{p'_o T_o} \right)$$

in which s_i is the specific heat of ice, and the other terms have the meanings previously given.

It will be interesting to note that the form of the adiabatic equation is:

1. For the dry stage,

$$\log p - a \log T = C, \text{ a constant.}$$

2. For a condensation stage,

$$\log p' - \frac{b}{p'} - a \log T = K, \text{ a constant,}$$

in which a and b are numerical coefficients, p the total pressure, and p' the partial air pressure.

The short hail or freezing stage is distinct from either of the others, though it may be represented approximately by an equation of the second or condensation type.

"Pseudoadiabatic" Convection.—Adiabatic expansion of the atmosphere obviously implies that all cloud particles, rain drops, and snowflakes are carried along with the identical air in the midst of which they were condensed. This condition cannot rigorously obtain in Nature at any level; neither do all the products of condensation, especially the smaller droplets, rapidly fall away immediately they are formed. Hence the actual process, if conduction, radiation, and absorption were negligible, would lie somewhere between the adiabatic, with all condensation products retained, and that special type of the nonadiabatic which Neuhoff and others have called pseudoadiabatic, where all such products are immediately removed, probably much nearer the latter than the former.

To reduce adiabatic to "pseudoadiabatic" equations it evidently is only necessary to drop the water and ice terms. This of course, automatically excludes the hail stage—it eliminates all water and therefore renders freezing impossible. Nevertheless the differences between the temperatures and pressures given by the two processes generally are small.

For convenience of inter-comparison the two sets of equations, adiabatic and "pseudoadiabatic," are here grouped together.

Dry stage

Adiabatic, $\log \frac{p}{p_o} = \frac{C_p + wC'_p}{A(R+wR')} \log \frac{T}{T_o}$

"Pseudoadiabatic," Does not exist, there having been no condensation.

Rain stage

Adiabatic, $\log \frac{p'}{p'_o} = \frac{Cp + ws_1}{AR} \log \frac{T}{T} + \frac{M}{AR'}\left(\frac{eL}{p'T} - \frac{e_oL_o}{p'_oT_o}\right)$

"Pseudoadiabatic," $\log \frac{p'}{p'_o} = \frac{C_p}{AR} \log \frac{T}{T_o} + \frac{M}{AR'}\left(\frac{eL}{p'T} - \frac{e_oL_o}{p'_oT_o}\right)$

Hail stage

Adiabatic, $\log \frac{p'_1}{p'_o} = \frac{M}{AR'T_o}\left(\frac{e}{p'_1}(L+F) - \frac{e}{p'_o}l - \frac{R'}{R}wF\right)$

"Pseudoadiabatic," Does not exist, there being no water and therefore no freezing.

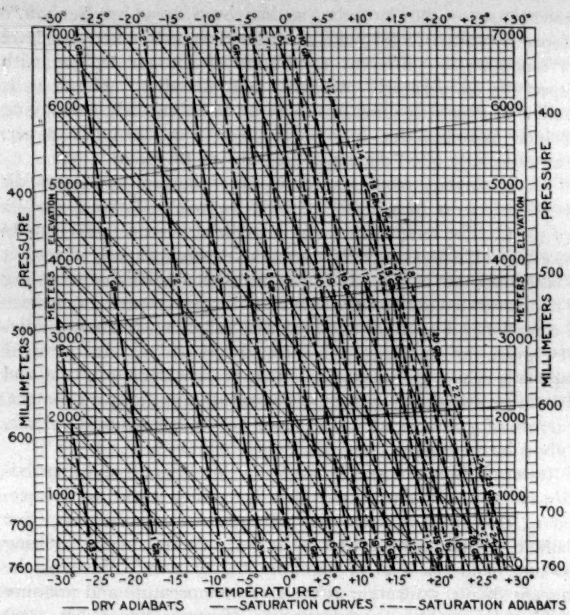
Snow stage

Adiabatic, $\log \frac{p'}{p'_o} = \frac{C_p + wsi}{AR} \log \frac{T}{T_o} + \frac{M}{AR'}\left(\frac{e(L+F)}{p'T} - \frac{e_o(L_o+F_o)}{p'_oT_o}\right)$

"Pseudoadiabatic," $\log \frac{p'}{p'_o} = \frac{C_p}{AR} \log \frac{T}{T_o} + \frac{M}{AR'}\left(\frac{e(L+F)}{p'T} - \frac{e_o(L_o+F_o)}{p'_oT_o}\right)$

It will also be convenient to have listed the several constants of these equations and their numerical values. If the unit of heat

FIG. 60.



Adiabatic diagram (Neuhoff).

is 1 calory, the heat necessary to raise the temperature of 1 gramme of water from 0° C. to 1° C., the values of these constants are:

$A = \frac{1}{4.19} \times 10^7$ ergs, nearly.
$F = 80$ calories, about.
$L = 600$ calories, approximately.
$M = 0.43429448$, for base 10.
$T = 273 +$ reading of centigrade thermometer.
$R = 28.71 \times 10^6$ ergs per gramme 1° C., nearly.
$R' = 46.42 \times 10^6$ ergs per gramme 1° C., closely.
$C_p = 0.241$, about.
$C'_p = 0.46$, roughly.
$s_1 = 1$, closely.
$s_i = 0.5$, approximately.

With these values various tables may be constructed for convenient use of the formulæ, as has been done by Neuhoff.[80] Proper hypsometric formulæ give the elevations above sea level corresponding to different conditions of the atmosphere with respect to temperature, pressure, and humidity. Hence it is possible to construct diagrams more or less accurately embodying all such calculations. Fig. 60, copied from Neuhoff's paper, is an especially good adiabatic diagram of this kind.

As is obvious from inspection, this diagram applies to all altitudes from 0 (sea level) to 7000 metres, and from −30° C. to +30° C. The temperature and altitude differences are equally spaced, and the pressure differences, therefore, unequally in respect to both the other terms. It is assumed that the adiabatic cooling of non-saturated air is at the rate of 1° C. per 100 metres increase of elevation, an approximately correct value, hence the dry adiabats, given in full lines for intervals of 10° C., are straight diagonals, while the saturation adiabats, represented by dot and dash, are considerably curved. The saturation moisture content, in terms of grammes of water vapor per kilogramme of dry air, is given by the broken lines.

Interpolations are readily made on the diagram and approximate values easily obtained by always starting from the intersection of the given temperature and pressure coördinates. For example, let the temperature be 20° C., the barometer reading 760 mm., and the relative humidity 55 per cent. Since, as the diagram shows, saturation at the given temperature and pressure would require about 14.6 grammes of water vapor per 1000 grammes of dry air, it follows that under the assumed conditions only about 8 grammes would be present. Hence the temperature, pressure, and altitude of such a mass of air rising adiabatically are given, through the first convective stage, by that dry adiabat that starts at the intersection of the initial temperature and pressure ordinates, 20° C. and 760 mm. The first stage terminates when saturation is attained, and therefore, in the present case, at the intersection of the given adiabat with the 8-gramme humidity curve at an elevation, as inspection shows, of rather more than 1100 metres and where the pressure corresponds to a barometric reading of about 625 mm. From this level up the conditions of the rising mass of air are given by a saturation

[80] *Loc. cit.*

adiabat, according to which the temperature will have fallen to 0° C. and the humidity to about 5.25 grammes at an elevation of approximately 2700 metres. The humidity decrease, 2.75 grammes per 1000 grammes of dry air, is the amount precipitated as water in the form of cloud particles and rain drops. If all this water is carried along, its latent heat of fusion will maintain the temperature at 0° C. through an additional rise of about 80 metres, but, as much of this water obviously must drop out, it follows that the actual conditions presumably are rather better represented by omitting the "hail stage," or by a continuous rather than a broken adiabat.

While this diagram gives approximately the relations between temperature, pressure, humidity, and altitude that obtain in regions of strong vertical convection, it does not closely represent them as they normally exist at other places. This is due partly to the horizontal component of air movement, as above explained, and partly to that constant emission and absorption of radiation that always precludes the existence in the atmosphere of strictly adiabatic conditions.

Why the Atmosphere Generally is Unsaturated.—It may, perhaps, seem strange that, in spite of the continuous and rapid evaporation from nearly all parts of the earth's surface, the atmosphere as a whole never becomes even approximately saturated. This condition, however, is a necessary result of vertical convection. Obviously whatever the temperature and relative humidity of a given mass of air at any point of its convectional route, its absolute humidity is less then, in general, than when its ascent began, by the amount of rain or snow already abandoned by it. That is, on the average, air in a convection circuit descends to the earth dryer than when it previously ascended from it. In short, convection, because it induces abundant precipitation is therefore a most efficient drying process; and because comparatively little precipitation is produced in any other way, convection alone prevents the atmosphere from becoming and remaining intolerably humid.

Summer and Winter Precipitation.—Vertical convection, essential as above explained to all considerable condensation, results from three distinct causes: (*a*) superadiabatic temperature gradients, due often to surface heating; (*b*) converging winds, as in the front half of cyclones; and (*c*) forced rise from (1) flow

over land elevations and barriers of cold air, (2) underrunning of cooler winds. The first or thunderstorm type of convection causes much of the summer precipitation of temperate regions, as also nearly all the rain of the tropics, while the second or cyclonic convection produces by far the greater part of winter precipitation, except, perhaps, that which occurs along the windward sides of the most favorably situated barriers. Also, during the colder season precipitation usually occurs lower down the barrier slope and may be induced by feebler cyclones or other storms than in the warmer. This is owing in part to the fact that generally there is less difference between the actual and dew-point temperatures during winter than during summer (a condition determined by the great seasonal temperature changes of continents with reference to the ocean), and therefore a less convection required in the first case than in the second to induce condensation, and partly to the greater rate of decrease of temperature with increase of latitude while the days are short than while they are long, a condition that favors winter precipitation by causing a greater fall of temperature during the winter season than any other for a given travel of the wind on the front or rainy side of a cyclone. That is, usually a less vertical convection and a less horizontal travel of the air—a feebler storm—suffices to induce precipitation during winter than during summer.

The contrasts, then, between summer and winter precipitation are manifold. A typical case may be illustrated by the following table:

Contrast Between Summer and Winter Precipitation.

	Summer	Winter
Rain	Usually.	Often.
Snow	Never.	Frequent.
Hail (ice lumps)	Occasionally.	Never.
Sleet (frozen rain)	Never.	Occasionally.
On barrier	High.	Low, and up.
Type of storm	Thunderstorm frequently	Cyclone.
Strength of convection	Strong, generally essential	Feebler, often sufficient.
Intensity of cyclone	Decided, usually essential	Slight, often sufficient.

(*To be continued.*)

A NEUTRAL-TINT AND VARIABLE-TINT SCREEN.*

BY

E. KARRER, Ph.D.,

Physicist, Research Department, United Gas Improvement Company.
Member of the Institute.

VARIOUS devices have been described for controlling the intensity of a beam of radiation. In particular, most of these devices are intended to allow changes in the intensity of light by an infinite number of steps, according to some simple law which shall be the same for any and all wave-lengths; *i.e.*, the screen shall be neutral.

Most of such screens depend upon the absorption of light chiefly by opaque, solid bodies. Reflection is depended upon in certain few cases. The Nicol prisms and piles of glass plates belong to the former, together with those recently considered by Mr. E. F. Kingsbury [1] and with photographic wedges.

Scattering is depended upon in the screens which decrease the light proceeding in a certain direction by diffusing it, and is important in certain glass wedges and in photographic wedges. A photographic film, when mounted so that it may be turned, is an admirable neutral-tint screen for short limits.

Solutions have never been made for neutral-tint absorbing screens, though it may be feasible to use opaque particles in a liquid, allowing them to arrange themselves under gravity or some other force and thus obtain a graduated wedge. Colloidal solutions that will jell might be used in this connection.

The chief feature of disadvantage in most of the neutral-tint screens is the low maximum transmission, which cannot be increased, or, if at all, only by decreasing the range of the screen.

In most of the cases cited the maximum transmission cannot be more than 50 per cent.

Having occasion, in recent work, to employ neutral-tint screens for use in a compact photometer, I was disappointed with the low maximum transmission of those available.

The neutral-tint screen described here is intended to overcome this disadvantage somewhat. However, the universality of the present screen is probably its chief point of recommen-

* Communicated by the Author.

[1] JOURNAL OF THE FRANKLIN INSTITUTE, vol. 181, March, 1916, p. 369.

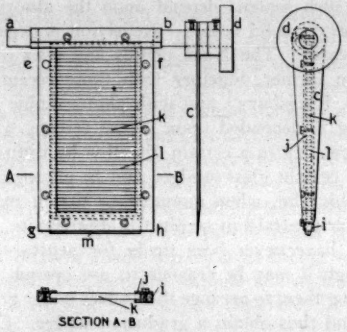
dation, for it can easily be made as a variable-tint screen for use in various experiments and practices where different tints of light are compared or matched.

A very great convenience in a screen is to be able to see an object through it as the screen here described allows. Many screens do not afford this.

A brief description of the present screen is as follows, taken in connection with Fig. 1:

The screen proper consists of small, rectangular glass bars (*k*), cut from a plate of glass, whose cut edges are ground so

FIG. 1.



Showing the construction of the neutral- and variable-tint screen.

as to be neatly laid together. Between the bars are laid some narrow strips of thin, opaque material (*l*); *e.g.*, black paper.

The glass bars are laid in a groove in a metal frame and held in place by a thin metal covering of the shape and size of the frame (*efgh*) and attached to it by means of screws. For rotating the screen an axis (*AB*) and a pointer (*C*) are provided.

The axis was placed at the end for adaptation to an existing mount where as long a pointer as possible was desirable without unnecessary lengthening of other parts.

d is a milled edge wheel by which to turn the screen.

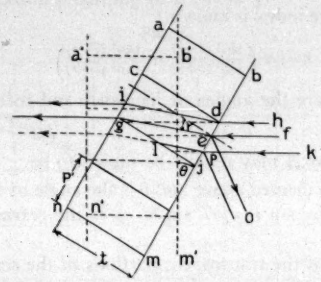
m is a metal plate with slots so that it may be moved inward to press the glass rods together.

An end view of a thin section taken out at AB is given to show the manner of holding the glass bars; i is the metal frame; j the clamping plate; k the glass bar.

In the right-hand picture is a view of the screen seen edgewise, where the symbols have been defined already.

When the screen is placed in a beam of light it will obstruct a portion of the light, depending upon the angle which it makes with the beam. The theory of it will be clear by reference to Fig. 2, where *abmn* is a longitudinal section of the screen. *cdgj* is the cross-section of a glass bar against whose sides are opaque films *cd* and *gj*.

FIG 2.



Showing the passage of light through the neutral-tint screen.

The thickness of the screen is designated by t; the spacing of the screen or width of glass bars by s.

The effective length of the bars in this screen is 3.16 cm.; t is 2.23 mm.; s, 1.42 mm.

If a beam of parallel rays of light 1 sq. cm. in cross-section is incident upon the screen, a maximum amount of it will be transmitted when the screen is in the position of $a'b'm'n'$. When it is inclined to the direction of the beam, a greater area of the opaque films will be presented to the beam and less of its energy will be transmitted.

Not only due to this absorption will the amount of energy transmitted become less as the screen is tilted, but also due to the reflection from the surfaces of the glass bars.

A ray of light *fe* incident upon the screen at an angle (θ) will be in part reflected (*eo*) and in part refracted and transmitted

(eg), while a ray kp will similarly be reflected and refracted, but absorbed by the opaque film gj.

If we let R be the per cent. of energy reflected by the glass surfaces, A that absorbed by the opaque films, S that scattered, and T the per cent. of energy transmitted, we may write $R+T+A+S=1$. When the glass bars are clear, with smooth plane surfaces, and the films are opaque, there is no scattering and $S=0$.

$$\text{So that } T=1-A-R \tag{1}$$

Both A and R are functions of the angle.

The values of R may be calculated by the Fresnel formula for light reflected from the surface of a transparent medium whose refractive index is known.

$$R=1/2\left(\frac{\sin^2(i-r)}{\sin^2(i+r)}+\frac{\tan^2(i-r)}{\tan^2(i+r)}\right) \tag{2}$$

where i and r are the angles of incidence and refraction respectively.

The value of A may readily be shown to be $\frac{t}{s}\tan r$ where t and s have been defined above and r is the angle of refraction and is related to θ by $\sin r=1/\mu \sin\theta$. μ is the refractive index of the glass.

The width of the transparent portions of the screen is $(s\text{-}ej)$, but $ej=t\tan r$.

The amount of light striking an opaque portion is proportional to the projected area $(t\tan r)\cos\theta$.

The number of such opaque portions struck by a beam of light of unit cross-section is $\frac{1}{s\cos\theta}$ if we neglect the thickness of the opaque film.

So that the amount of light absorbed is proportional to the product of these quantities, or $\frac{t}{s}\tan r$.

$$\text{Then } T=1-\frac{t}{s}\tan r-R \tag{3}$$

In Fig. 3 is shown the effect of changing the ratio.

t/s, curve A, was obtained with a screen where $t/s=1.03$, while curve B was obtained with the same screen after making the glass bars narrower, such that t/s is 1.57.

The effect of the refraction of the light by the glass is to extend the scale. Curve D, Fig. 3, shows the curve for $t/s=1.57$

when the glass bars are removed. The index of refraction now is unity and $r = \theta$, so that formula 2 becomes

$$T = 1 - t/s \tan \theta \qquad (4)$$

For $R = 0$ also.

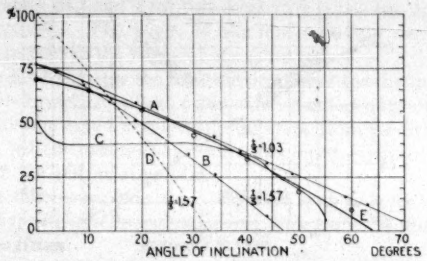
In Fig. 4 are shown separately the three factors of importance which affect the light passing through the screen.

The reflection has been calculated from equation (2), using 1.61 as the refractive index which was measured for one of the rods.

The absorption has been calculated, for $\mu = 1.61$ and $t/s = 1.57$

The transmission curve is obtained from the curve for reflection and absorption according to formula 3.

FIG. 3.



Correction has been made for the thickness of the films and is included in the curves for reflection and absorption.

There were certain other losses in the screen due to the fact that the edges were not sharply ground and due to the fact that during the process of grinding the surfaces of the bars were somewhat mutilated.

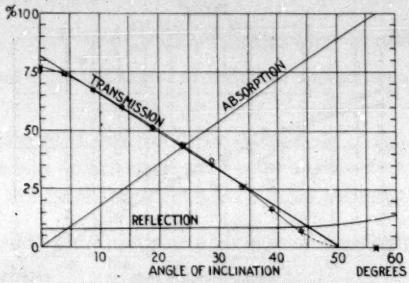
These losses probably account for the discrepancy between calculated and experimental values. The latter were uniformly 11.9 per cent. lower than the former. In the curves for the transmission in Fig. 4, the heavy line represents the calculated values after multiplying by 0.881. Several screens were made and their transmission factors obtained both for parallel rays and for diffused rays. The curve in thin line with the circles and crosses represents a typical case. The crosses are observations with parallel rays, the circles observations with well-diffused rays.

The differences are not great and are within the accuracy that was sought for the present determination.

The experimental curve departs from the theoretical curve at both extremities, being generally lower in each case. This is due probably in part to such imperfections already noted and to scattering and diffraction. Beyond 50 degrees, where the experimental values become higher, diffraction effects are probably present and scattering by the opaque films, some of which were slightly translucent, together with reflection by the black films at great angles of incidence. The black film in this screen was the ivory black of ordinary "water colors."

The amount transmitted at 56.75° is 0.004 per cent.

FIG. 4.



Having now described the general structure and characteristics of the screen and the manner of operating it, I shall point out a few modifications of it that may be important in heterochromatic photometry, in colorimetry, in illuminometry, and in pyrometry.

The characteristics may be altered by using bars whose cross-section is not rectangular. In Fig. 3, curve C is shown the transmission curve of a screen made of round rods of glass.

The round rods were ground flat where they lay in contact. The opaque film was black lacquer. The rods were not of uniform size and shape. The mean diameter of the rods was about 1 mm. The light transmitted by this screen was diffused, and objects could not be seen through it. The most characteristic feature of it is the quite constant transmission for wide angular movements. This may be of importance when we consider the next modification of it for use as a variable-tint screen.

If these rods were made of quartz, we should have a neutral-tint screen for the ultra-violet radiation.

If, instead of opaque absorbing films, we were to insert transparent and colored films, we would have a means of varying the color of the beam of light transmitted; for, as the screen is tilted, a greater portion of the beam is caused to pass through the colored films. A screen was constructed of rectangular bars with layers of a red gelatine film between them. The gelatine film transmitted chiefly in the red, but also to a very slight extent the blue.

There was no selection possible in using the red film, being one that is commercially used for theatrical effects; so that the results given below that were obtained with this screen are only roughly indicative of what may be accomplished by the use of the variable-tint screen when properly constructed.

The values of t and s for this screen are 0.113 cm. and 0.143 cm. respectively. The edges of the film were not very evenly laid with respect to the edges of the glass bars.

Curve E of Fig. 3 is the transmission curve for the red screen obtained by myself by direct comparison method of photometry. Its transmission is not very greatly different from the first screen described, where opaque films were employed—indicating high density of the red gelatine film.

When this screen was used, together with a layer of three plates of very light yellow glass, a very wide range of illuminants could be matched.

The transmission of the yellow glass was 53.1 per cent. for a tungsten point source lamp operated at normal voltage.

A tungsten filament lamp could easily be made to appear like the point source 4-watt lamp.

A point source tungsten 100 watts, operated at 120 volts, could easily be matched in an intensity of illumination given by the 4-watt carbon stereopticon lamp operated at 80 volts at a distance of 42.9 cm.

The variable-tint screen was inclined about 28.7 degrees. At this angle its transmission factor is 47 per cent., so that the total light transmitted by the color screen was 25 per cent., which is very low. However, no refinements were sought in these preliminary trials of the screen.

A Welsbach mantle could also be excellently matched in color with the same carbon lamps.

The use of the additional yellow screen with the variable-tint

red screen on the side of the lamp, whose light was to be altered so as to match the carbon lamp, made it possible to have either the first or the second source appear either yellower or redder than the other.

In conclusion I wish to express my appreciation for the valuable criticism and suggestions given by Mr. E. F. Kingsbury in this work and for the encouragement given by Mr. C. O. Bond.

By means of two or three screens with a suitable source of light, wide ranges in tint may be matched.

Two screens have been constructed in which the colored medium was the dyed gelatine filters used in color projection. These red and green screens were the Wratten stained gelatine light filters, Series No. 60, Reference P, and Series No. 25, Reference A, respectively, which may be procured from the Eastman Kodak Company.

A variable-tint screen with much greater fineness of structure but with lower maximum transmission may be made by the use of photographic plates.

An ordinary negative is made having a sufficient number of opaque lines to give the desired fineness (say 20 to the inch). The lines are as wide as the clear spaces between them.

From this negative another may be made exactly its counterpart, where, however, the opaque lines are colored. This is brought about by the phenomenon known to color photographers of the hardening of gelatine when treated with a bichromate salt.

The gelatine on a plate so treated is rendered more or less insoluble when exposed to light, and after washing and drying may be stained by immersion in dyes.

Having these two plates—the one with spaces opaque, clear, the other with spaces colored, clear—one superimposes them in such a way that the opaque lines of the first register with the colored lines of the second. In this position they are suitably cemented.

When this screen is mounted as described above it will present a different tint, depending upon the angle of inclination.

These experiments were not completed when work in this direction was halted.

UNITED GAS IMPROVEMENT COMPANY,
Physical Laboratory,
Philadelphia, Pa.,
October 26, 1917.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

METRIC PUBLICATIONS.

In view of the great demand for information on the metric system for use of our forces in France, and for the use of the War and Navy Departments in this country, as well as for manufacturers of war materials, the Bureau has been distributing, on request, copies of its publications on the International Metric System. These include a descriptive pamphlet, a graphic chart, a metric comparison scale, a circular giving definitions and tables of equivalents, a report of the metric system in the export trade, and a supplement to the table of equivalents giving the millimetre-inch equivalents. In view of the order recently issued by the Ordnance Department, adopting the system for use for specified purposes, the demand for the charts for instruction of officers, aviators, and others has been especially heavy.

WAVE-LENGTH MEASUREMENTS IN SPECTRA FROM 5600 TO 9600 Å.[1]

By W. F. Meggers.

[ABSTRACT.]

During the past thirty years the spectra of the chemical elements have been quite thoroughly investigated in the wave-length region to which ordinary photographic plates are most sensitive—that is, from 2000 Å to 6000 Å (Å = angstrom = 0.0000001 mm.) This was made possible by Professor Rowland's invention of the concave grating and the establishment of his system of standard wave-lengths. Since 1904 a new system of wave-length standards—the international system—has been established and the wave-lengths from 2000 Å to 6000 Å of many spectra have been re-measured in international angstroms.

* Communicated by the Director.

[1] Scientific Paper No. 312, Bureau of Standards.

The long waves have never been so extensively or carefully investigated, because of the great difficulty in photographing them. Measurements of the wave-lengths of some of the strong lines in the red and adjacent infra-red regions of the spectrum have been made by using radiometers or phosphoro-photography to detect the waves. These methods, however, are difficult and yield results which are not in very good agreement. It is generally conceded that nothing can compete with direct photography for the accurate determination of the structure and wave-lengths of spectral lines.

The photographic work on long wave-lengths has been done principally with ordinary photographic plates which have been specially treated with dyes to make them sensitive to these long waves. Such dyes as alizarin, nigrosin, cyanin, and dicyanin have been used for the purpose. Up to the present, however, comparatively few spectra have been investigated by this method. In most cases photography with stained plates has not registered waves much longer than 8000 Å, although it is possible to reach much longer waves by this method. Furthermore, such work has been done chiefly with the low dispersion of prisms or concave gratings with small radius of curvature, and very few long wave-lengths have been measured in international angstroms. By using the photographic method with interferometers or with larger gratings, accurate information concerning the spectra of the elements can be extended to regions beyond 9000 Å without much difficulty.

Some work on spectroscopic analysis at the Bureau of Standards led to a photographic investigation of the spectra of some of the elements in the region of longer wave-lengths. The photographic sensitizers dicyanin and dicyanin A were used and found to be of great value in photographing spectra between the wave-length limits 5600 Å to 9600 Å. This work was begun with the plan of studying the longer waves of the spectra of elements commonly found in iron as impurities, such as nickel, cobalt, chromium, manganese, copper, titanium, vanadium, silicon, calcium, and carbon. The success in photographing these led to the photography of the spectra of the following elements in addition to those mentioned: lithium, sodium, potassium, rubidium, cæsium, beryllium, strontium, barium, and magnesium. Thus

the arc spectra of twenty of the chemical elements were photographed from 5600 Å to 9000 Å or beyond.

Accurate measurements of wave-lengths to 8824 Å in the arc spectrum of iron have been made with interferometers by Burns. Similar measurements have been made to 8210 Å in the barium-arc spectrum by Werner. These spectra do not contain a sufficient number of evenly distributed and sharp lines in this region to recommend them as entirely satisfactory for standards. A photographic survey of the spectra of the elements may disclose a more satisfactory source for long-wave standards.

Some of the spectra which were photographed, notably those of cobalt, nickel, titanium, vanadium, manganese, and chromium, were found to have sharp lines whose wave-lengths can be more accurately obtained with interferometers than from the grating photographs made in this work. Furthermore, the number, distribution, and intensity of lines in this part of the cobalt-arc spectrum were found to be more satisfactory than in the iron-arc spectrum.

If the sharpness of these cobalt lines be examined with the interferometer, the cobalt arc may be found superior to the iron arc as a source of long-wave standards. The wave-length measurements in these sharp-line spectra will therefore be postponed until the interferometer is applied.

Many elements, especially the alkali metals, have spectra the greater part of whose lines are broad, diffuse, reversed, or unsymmetrical. A careful study of the long-wave spectra of some of these elements has been made.

The wave-lengths have been measured in international angstrom units, and the results are probably as accurate as the structure of the lines will permit. These results are of special interest because of the regularities and series relationships which exist in the spectra of the II and III groups of elements in the periodic system. The apparatus and method used in photographing and measuring these spectra are described in this paper, and the results are given for lithium, sodium, potassium, rubidium, cæsium, copper, beryllium, calcium, strontium, barium, and magnesium.

THE PROPERTIES OF PORTLAND CEMENT HAVING A HIGH MAGNESIA CONTENT.[2]

By P. H. Bates

[ABSTRACT.]

A SERIES of cements was burned in the Bureau's experimental rotary kiln in which the limestone used in the raw material was replaced in part or in whole by dolomite. A magnesia content as high as 25 per cent. was obtained in the resulting cement, and the clinker was examined petrographically. The constituents present, their amount, and the character of their formation were carefully studied. The clinker was also ground and the resulting cement subjected to the usual tests for physical properties. The results show that cements not exceeding 8 per cent. in magnesia content will produce concretes of satisfactory strength at the end of 1½ years. With this amount of magnesia, monticellite and spinel (constituents not present in cements of lower magnesia content) appear; and these cements seem to hydrate with a large increase in volume.

COMBINED TABLE OF SIZES IN THE PRINCIPAL WIRE GAUGES.[3]

By R. Y. Ferner.

THIS table combines in one series the sizes in the American (B. & S.), Steel, Birmingham (Stubs'), British Standard, and Metric Wire Gauges, arranged in order of sizes (diameters) of wires. It gives the diameters of all the gauge numbers in these five systems in mils, millimetres, and inches, also the cross-sections in square mils, circular mils, square millimetres, and square inches. The table is specially useful to manufacturers who wish to determine the nearest equivalent in American or British gauge sizes of wires specified in millimetres or square millimetres, or *vice versa*.

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[2] Technologic Paper No. 102, Bureau of Standards.
[3] Circular No. 67, Bureau of Standards.

NOTES FROM NELA RESEARCH LABORATORY.*

THE MEASUREMENT OF TRANSMISSION FACTOR.

By M. Luckiesh and L. L. Mellor.

In a previous paper [1] one of the authors discussed the conditions which affect the value of the reflection-factor of a surface not perfectly diffusing, and pointed out the difficulties in making such measurements. It was concluded that the measurement of reflection-factor should be determined in general for highly diffused light. A similar investigation has been prosecuted with the purpose of studying the measurement of transmission-factors of ordinary glasses of the partially diffusing type, such as sand-blasted, etched, ribbed, and pebbled glasses. In both investigations it was aimed to devise a simple apparatus for determining these values by measuring a single quantity after the apparatus is duly calibrated. For the measurement of transmission-factor the integrating sphere was an essential part of the apparatus. The transmission-factors were determined both for (1) a narrow pencil of light directed perpendicularly to the glass specimen and (2) hemispherical illumination or highly diffused light. In general, as was to be expected, the transmission-factor was less for diffuse illumination than for the perpendicular pencil of light. Furthermore, in the case of the narrow pencil of light, the transmission-factors of these glasses were less when the smooth side faced the light-source than when the rough side faced the light-source. This difference is very apparent for certain ribbed glasses, being as much as 50 per cent. It amounted to about 5 per cent. for the sand-blasted and etched glasses. The difference is readily accounted for in the case of a crystal glass with one rough surface by assuming that, when the smooth side faces the light-source, the rough side reflects a certain amount of light owing to the similarity of many of the rough points to reflecting prisms. This would only obtain at the glass-air surfaces and not at the air-glass surfaces in case the specimen were reversed. In most cases the transmission-factors were between 0.70 and 0.85.

* Communicated by the Director.

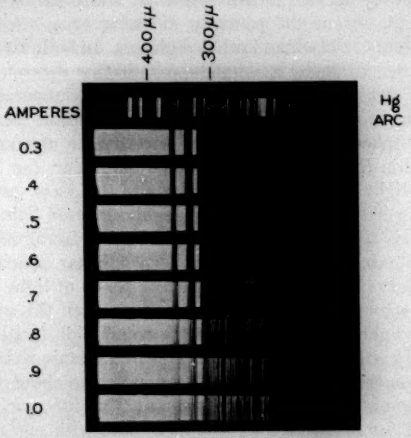
[1] *Electrical World*, 69, p. 958 (1917).

A number of simple photographic procedures have been devised for illustrating the physical and optical characteristics of specimens of glass of this type.

THE ULTRA-VIOLET SPECTRUM OF THE TUNGSTEN ARC.

By M. Luckiesh.

ALTHOUGH much desired, there is not available a light-source emitting a continuous spectrum between 200 and 400μμ. The quartz mercury arc emits many lines in this region, but the spectrum does not approximate continuity. Some arcs (particularly



flame arcs) and electric sparks provide ultra-violet spectra which find many uses, but these are not usually steady sources. The ultra-violet spectrum of tungsten is very rich in lines in this region, and, inasmuch as a tungsten arc can be made to operate quite steadily in certain gases, its spectrum was studied with the aim of determining the adaptability of such an arc to various problems.

A glass bulb was provided with a plane quartz window oppo-

site the tungsten electrodes. Commercial argon, containing about 20 per cent. nitrogen, was admitted to the evacuated bulb at a pressure of 20 cm. of mercury. Spectrograms were made for currents varying from 0.3 ampère to 5.0 ampère. For this particular arc the ultra-violet energy between 200 and 300$\mu\mu$ is relatively weak for the lowest currents at which the arc operates. The energy in this region apparently increases more rapidly than the near ultra-violet energy as the current is increased until about one ampère is reached. In the illustration the spectrograms are shown for currents up to one ampère, the exposure being constant for the entire group. The spectrum between 300 and 400$\mu\mu$ may be considered approximately continuous for some purposes, although shorter exposures show that it is somewhat fluted in character.

The arc voltage varied from 28 to 16 volts as the current increased from 0.3 to 5.0 ampères respectively, thus consuming from 5 to 80 watts. This arc was quite steady and is adaptable to many physical and chemical problems. It may be made much more powerful to suit requirements.

A Thermo-electric Standard Cell. C. A. HOXIE. (*Proceedings of the American Institute of Electrical Engineers*, vol. 37, No. 2, p. 57, February, 1918.)—Most engineers are familiar with the uses and limitations of standard cells of the Clark or Weston types. Neither of these cells will function at freezing- or boiling-point temperatures, and both are easily damaged if an appreciable current is drawn, as by accidental short circuit. Though the thermo-electric cell is not, strictly speaking, a primary standard or source of electromotive force, as the Clark or Weston cell, it is at least free from these drawbacks. It may be more properly classed as a secondary standard, its value being determined by comparison with a primary standard.

The cell consists essentially of a circuit comprising a drop resistance, across which the standard electromotive force is obtained, a heating filament, and a balancing resistance across which the electromotive force of a thermocouple adjacent to the heating filament is balanced. The potential across the balancing resistance is a linear function of the current, while that of the thermocouple varies approximately according to the second power of the current. Balance is therefore obtained for some fixed value of current which determines the standard electromotive force across the drop resistance. Means are provided for compensating for the temperature coefficient of the cell. The standard cell has been successfully applied to potentiometers designed for thermocouple work.

Canvas Tubing for Mine Ventilation. L. D. FRINK. (*Mining and Scientific Press*, vol. 116, No. 7, p. 223, February 16, 1918.)—Metal tubing with blower or exhaust fans has long been used for supplying air to dead ends where natural ventilation is impossible. In Butte, canvas tubing is now used extensively because it is found that it has many advantages not possessed by the metal. Although the use of flexible tubing is not new, it has not been generally used in mining operations. Recent improvements, however, in the canvas itself, in the joining of sections, and in the manner of suspension have so increased its usefulness that it promises to add much to the efficiency of mining. A product is now on the market that is impervious to air and fireproof, and provided with a system of jointing that permits it to be put up or taken down in a few seconds.

Connections were first made by slipping the ends of adjacent sections over a 6-inch metal hoop and holding the canvas in place by wiring. Later a more efficient and secure joint was made by sewing-in at the ends of each section a flexible contracting ring. These rings are alike, and the joint is made by contracting one ring and forcing it past that of the adjacent section. When released it assumes its normal diameter and cannot be withdrawn past the neighboring ring. In the hem of the tubing, at intervals of three or four feet, grommets or eyes are inserted, and in these are fastened wire clips or hangers. By means of these hangers the tubing can be hung rapidly to a messenger or suspension wire. Each section is provided at the ends with grommet eyes closed with corks for the removal of water of condensation.

Airplane Dopes. G. J. ESSELEN, JR. (*The Journal of Industrial and Engineering Chemistry*, vol. 10, No. 2, p. 135, February, 1918.)—"Dope" is the term applied to the varnishes used on the wings of airplanes to render the fabric taut and waterproof. An airplane wing is made by covering a framework of the proper size and shape with a linen or cotton fabric. There are then applied to the fabric several coats of a suitable varnish, of which the base is either cellulose acetate or cellulose nitrate. The term "dope" seems to have arisen in the slang of the factory workman, but is now firmly fixed and is used to distinguish the cellulose acetate or nitrate "dopes" from the spar varnishes made up of gums and oils, which are sometimes used as a finishing coat. The chief function of the dope is to tighten up the fabric and give a smooth, taut, waterproof surface, resistant to the weather, and preferably also to oil and gasoline. It also adds to the tensile strength, the percentage increase depending somewhat upon the strength and character of the fabric and upon how much the fabric was stretched before doping. In Europe only acetate dopes are used, and it appears to be only a matter of time when the users of airplanes in this country will demand that every possible factor of safety be taken advantage of, which will mean the use of a non-inflammable dope.

NOTES FROM THE PHYSICAL LABORATORY OF THE UNITED GAS IMPROVEMENT COMPANY.*

A MODIFIED GAEDE GAUGE.

By Enoch Karrer.

THIS is an improvement in the gauge described previously by the author.[1]

In the gauge previously described all rubber parts of the short Gaede gauge were eliminated by the use of a ground-glass joint.

The present improvement consists in eliminating the ground-glass joint. The mercury reservoir is a steel cylinder, connected to the compression chamber by means of a small steel tube. This small steel tube has a helix which allows of mechanical freedom sufficient so that the mercury reservoir may be raised and lowered the desired height.

The compression chamber, with its calibrated capillary tube, is made of glass as before. The connection between the glass and steel parts may be accomplished by using hard wax, by a platinum cylinder connection, or by soldering.

This manner of using a mercury reservoir is suggested for other apparatus where either adjustable volume or pressure is required.

Development of the Steel Car. H. P. HOFFSTOT. (*Railway Age*, vol. 64, No. 9, p. 461, March 1, 1918.)—The change from the use of wood to steel in the construction of coal cars in America was extremely gradual in its development, although many years ago a few all-steel cars were built and placed in operation by some of the steel companies. In the early nineties C. T. Schoen commenced making pressed-steel car shapes in his little plant in lower Allegheny, and for years supplied the railroads with pressed-steel centre plates, side bearings, stake pockets, push-pole pockets, etc., for use in connection with the construction of wooden cars. During the same time The Fox Plant in the same locality was furnishing pressed-steel trucks and truck specialties to railroads for use on wooden equipment.

About 1895 Mr. Schoen conceived the idea of building steel cars on a large scale. The following year the first steel cars were ordered by the Pittsburgh, Bessemer and Lake Erie Line, and shortly after by the Pittsburgh and Western and the Pittsburgh and Lake Erie.

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* Communicated by the Manager.

[1] *Physical Review*, vol. vi (1915), p. 51.

It is therefore to the foresight and initiative of the officers of these companies that a great measure of the credit for bringing about the change from the wooden to the all-steel car must be given. The demand for this type of car grew rapidly, and the new construction virtually revolutionized railroad traffic in this country.

The first hopper cars were built to carry coal, and, while stencilled "50 tons," were hardly of 40 tons capacity, so far as present M. C. B. requirements are concerned. Probably 85 to 90 per cent. of these cars are still running after 20 years of service. Railroads are continually demanding cars of heavier capacity so that the increasing volume of freight can be more economically handled. The 70-ton car has come into general use, and several thousand 90-ton cars are in operation on at least one well-known railroad, which is also experimenting with a 100-ton car. Many 100-ton coal cars are now in operation on short lines about steel mills, and one road has now under test four cars of 120 tons capacity.

An Improved System for Lighting Interurban Trolley Cars. W. J. WALKER. (*General Electric Review*, vol. 21, No. 2, p. 124, February, 1918.)—The annoying variations in the intensity of lighting of interurban trolley cars resulting from variations in the trolley voltage is a familiar defect of the lighting equipment usually employed in this service. Apart from the discomfort produced by variations of the interior illumination of the car, with the high speeds prevailing on interurban railways, it is essential for safety to maintain a satisfactory headlight. The incandescent headlight would easily meet service requirements were it not for the trolley voltage variation, and there is obviously need of some device for controlling the voltage of the lighting circuits.

The General Electric Company has developed and recently placed on the market a motor-generator set that is peculiarly suited to railway car lighting, in that the generator provides a practically constant voltage over wide variations in speed. On a typical third-rail installation very dense traffic movements cause wide voltage variations, with inadequate car illumination and poor headlight protection. The third-rail gaps are a further source of annoyance, causing repeated blinking of the interior lights and interference with the headlight. Under these conditions the voltage ranges from 625 to 150 volts, or from glaring brilliancy to near-darkness with the usual series equipment, while the motor-generator set is maintaining practically constant interior illumination down to 350 volts and a readable interior as low as 200 volts. At 150 volts the headlight is projecting 700 feet, and from 350 to 650 volts a distance of 1300 feet. With the series system, the light is out at 150 volts and the projection between 350 and 650 volts varies from 350 to 1000 feet. In other words, the low-voltage equipment is furnishing at 350 volts at the trolley as good interior illumination and a considerably better headlight than the series system furnishes at any voltage.

NOTES FROM THE RESEARCH LABORATORY. EASTMAN KODAK COMPANY.*

THE SENSITOMETRY OF RÖNTGENOGRAPHIC MATERIALS.[1]

By Millard B. Hodgson.

[ABSTRACT.]

THE measurement of the sensitiveness of materials used in ordinary light-photography has already been reduced to a more or less exact science. In the system of photographic sensitometry developed by Hurter and Driffield, the important photographic constants may be expressed numerically with but little difficulty. It has been realized by investigators in Röntgen materials that the following factors could be investigated precisely and mathematically:

(*a*) Sensitiveness or speed.
(*b*) Contrast.
(*c*) Relation between sensitiveness, contrast, and wavelength of X-rays.
(*d*) Development characteristics.
(*e*) Fluorescent screen efficiency.

The chief obstacle to making accurate sensitometer exposures to X-rays lies in the difficulty of making consecutive exposures accurately. In white light and sensitometry, a simple rotating opaque sectored disk, with the openings proportional to the progression of exposures, may be interposed between the light-source and the plate and a series of exposures obtained simply and accurately. With the available Röntgen equipment such procedure is impossible. The current furnished to operate the tube efficiently is pulsating, with the maximum frequency usually 60 cycles per second. Therefore, by interposing the rotating sectored disk in front of the tube operated by such pulsating current more or less synchronism occurs and grave errors follow. The most feasible method of working is by moving the plate itself by intermittent motion across the path of the Röntgen-ray beam in such

* Communicated by the Director.

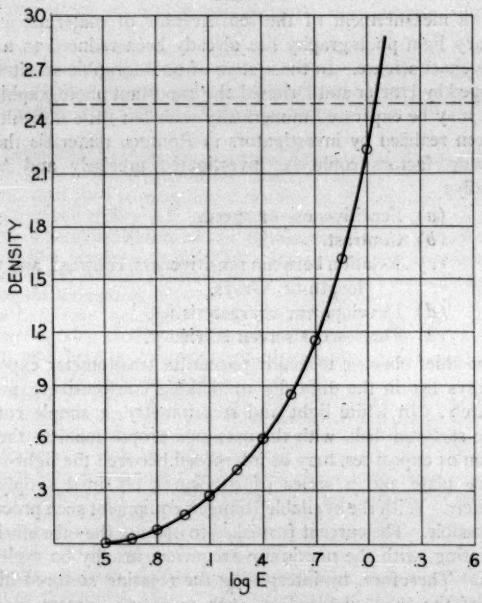
[1] Communication No. 63 from the Research Laboratory of the Eastman Kodak Company, published in *American Journal of Röntgenology*, 1917, p. 610.

manner that a known progression of exposures is given, controlled to the desired accuracy.

In the sensitometer adopted for the present work, the photographic plate is moved in this manner, the length of the exposure steps being controlled by an actuating electromagnetic mechanism.

For the study of Röntgen emulsions it was found most convenient to use an exposure progression of consecutive powers

FIG. 1.



of the square root of two. The Röntgen-tube circuit was connected to a solenoid switch, this switch being operated at the proper time by the sensitometer mechanism. The entire operation of exposure was thus governed to within an error of three per cent.

In plotting the density values of the resultant exposure strips, no absolute values are assigned to the points along the abscissæ, the curve being located merely by the known progression of

exposures given assuming an arbitrary exposure unit. Fig. 1 shows such a characteristic curve of the plate (Seed X-ray), obtained under the following conditions:

Tube—Medium focus Coolidge, 3-inch diaphragm stop.

Voltage—Ca 50,000.

Development — Five minutes at 70°, Elon-Hydrochinon formula.

It will be noticed that the type of curve is somewhat different from that usually obtained from white light exposure. The maximum density is beyond any which is optically measurable, even with the most intense light-source, the curve sweeping in a close approximation to a parabola, until a density of 5.0 or more is reached.

For average röntgenographic research, however, the portion of the curve to be considered is only that limited by such a density as can be seen through the average viewing frame. This is a density of about 2.5.

The method has been applied for the study of variation in the photographic effect of varying hardnesses or wave-lengths of X-rays. With the present types of X-ray emulsions the characteristic density exposure curve has been found to increase in slope or contrast with the softness of the tube; that is, with an increase in wave-length. The rendering power of the plate from these latter curves has been found to depend both upon the plate itself and the tube hardness. The method presents an accurate means for the measurement of intensifying screen efficiency.

Application of Concrete to Shipbuilding. ANON. (Monograph issued by Portland Cement Association, December, 1917.)—The pressing need for ships and the existing congestion in American shipyards have led to a consideration of the possibility of utilizing other materials than wood and steel for shipbuilding. Reinforced concrete is a most promising alternative, and its application to the construction of ships has of late received much attention. Although the possibilities of reinforced concrete as applied to shipbuilding are not widely known as is its use in building construction, at the present time nearly every country in the world is making some use of reinforced concrete in that field.

To what extent the development of concrete shipbuilding has taken place may be gathered from the operations of the San Francisco Shipbuilding Company, incorporated to undertake the construction of sea-going vessels of concrete. This company is now

building an ocean-going cargo vessel of nearly 5000 tons, that will be about 330 feet long, with a beam of 46 feet. In constructing this vessel the reinforcement was welded together, thus reducing to a minimum the quantity of steel required by avoiding the lap that otherwise would have been necessary. Plans for this work were developed by Allan McDonald, of McDonald & Kahn, San Francisco. The original drawings indicated that the reinforcement used weighs less than the bolts needed in a wooden ship of equal dimensions, and that the hull will weigh less than that of a wooden ship. The motive power will be supplied by a 2500-horsepower turbine equipped with reduction gears.

Initial Current Obtained in Incandescent Lamps. C. J. BERRY. (*Electrical World*, vol. 71, No. 9, p. 459, March 2, 1918.)—The resistance of the filament of a tungsten lamp is many times greater when the lamp is lighted than when the lamp is not connected in the circuit. The ratio of hot to cold resistance is, approximately, for a vacuum-type tungsten filament, 11.5 to 1, and for a gas-lamp tungsten filament, 14.6 to 1, while for an untreated carbon filament the ratio is 0.5 to 1. When tungsten-filament lamps are first thrown in circuit, there is an initial rush or "overshooting" of current caused by the filament resistance of the cold lamp being low as compared to the resistance it has when the lamp is lighted.

The initial current under constant voltage conditions at the lamp is not as many times greater than the normal current as the ratio of hot to cold resistance. Line resistance and reactance drops, and also the behavior of the electrical apparatus supplying the energy, are factors which decrease the effective voltage at the lamp, thereby keeping the current from rising to a high degree. The higher-wattage lamps do not overshoot to so high a percentage above normal value as the lower-wattage lamps. The maximum current value is reached in a very short interval of time, varying from 0.0004 to 0.003 second. The current, after reaching its maximum value, immediately starts to resume its normal operating value, and this is reached in about 0.1 to 0.2 second, depending upon the size of the lamp.

With an alternating current, there is a marked distortion of the current wave form due to the alternating and cooling of the filament. The initial current rises to different percentages, depending upon the point of the voltage wave at which the lamp is thrown in circuit and also upon the condition of the magnetism of the transformer before the switch is closed. The overshooting occurring with vacuum-type lamps is slightly less than that taking place with gas-filled lamps, since the filament temperature of the gas-filled lamp is higher than the operating filament temperature of vacuum lamps. The blowing of fuses or the opening of circuit breakers can be avoided when the protective apparatus is of proper rating and set correctly, and has a small time-factor element.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE APPLICATION OF OPTICAL METHODS OF IDENTIFICATION TO ALKALOIDS AND OTHER ORGANIC COMPOUNDS.

By Edgar T. Wherry.

[ABSTRACT.]

OPTICAL-CRYSTALLOGRAPHIC methods of identification have been used heretofore chiefly in connection with minerals, although their applicability to synthetic substances has been pointed out by several recent writers. Dr. F. E. Wright, in particular, has made preliminary examinations of several alkaloids, and shown the probable value of this method. The present writer is working out this method in detail, and applying it to the varied problems of the food and drug analyst. The paper abstracted deals especially with the methods of work which have been found appropriate in connection with alkaloids and related substances.

A simple chemical or petrographic microscope, provided with revolving stage, Nicol prisms, Abbé condenser, sub-stage diaphragm, selenite plate, etc., is used. The observations made are as follows: in ordinary light, color, crystal habit, angles, cleavage, and refractive indices are observed. For the determination of the indices the immersion method is used, and, as the alkaloids in general are soluble in the immersion liquids ordinarily applied to minerals, special liquids are required. It has been found that solutions of potassium-mercuric iodide in diluted glycerine are satisfactory for many substances. The determinations are made by diminishing the light by the sub-stage diaphragm and bringing a grain lying in a definite crystallographic position into focus; then, on raising the microscope tube slightly, a band of light will pass into that substance, crystal or liquid, having the higher index in that direction. Successive liquids are tried until no light moves in either direction, when the index of the grain is equal to that of the liquid, which is known.

By inserting the crossed Nicol prisms observations may be made in parallel polarized light, comprising the extinction angle,

* Communicated by the Chief of the Bureau.

strength of double refraction, and sign of elongation. By using, in addition, a high-power objective, inserting the condenser and removing the eyepiece, the interference phenomena in convergent polarized light are obtained. From the character of the figures it may be determined whether the substance is uniaxial or biaxial, whether its sign is positive or negative, and to what extent it exhibits dispersion.

Before measuring these optical properties the substances must be purified, and the effect of the solvent from which they are crystallized must be considered, for solvent-of-crystallization is frequently taken up, modifying the crystallographic properties considerably. When working with very minute amounts of alkaloids it is convenient to extract them with benzene. The solutions are allowed to stand until reduced to small bulk. Large drops are then placed on several microscope slides and covered at once with small cover-glasses. Evaporation then takes place and the alkaloid crystallizes out round the edge of the cover. After the solvent is completely gone the immersion liquids may be introduced and the usual observations made. The data obtained in this way with the four cinchona alkaloids are to be published in a separate paper.[1]

THE IDENTIFICATION OF THE CINCHONA ALKALOIDS BY OPTICAL-CRYSTALLOGRAPHIC MEASUREMENTS.[2]

By Edgar T. Wherry and Elias Yanovsky.

[ABSTRACT.]

THE probable value of optical-crystallographic measurements for the identification of alkaloids difficult to distinguish by chemical means being evident, the cinchona alkaloids—cinchonine, cinchonidine, quinine, and quinidine—have been exhaustively studied from this point of view. Samples were purchased on the open market and purified and identified chemically by the junior author, the optical properties being then measured by the senior author.

[1] To be published as a Professional Paper by the United States Department of Agriculture.

[2] Read at the November, 1917, meeting of the Association of Official Agricultural Chemists. To be offered for publication in the *Journal of the American Chemical Society*.

For determining the refractive indices by the immersion method, solutions of potassium-mercuric iodide in 50 per cent. glycerine were used.

The four alkaloids were found to be quite distinct in properties, and to be readily distinguishable. For instance, if crystallized from benzene and immersed in a liquid with refractive index 1.670, quinine is recognized at once by crystallizing in needles, all the refractive indices of which are much lower than that of the liquid, and which show between crossed nicols only first-order polarization colors, indicating the double refraction to be very low. Cinchonidine is in rods or plates, with the refractive index lengthwise somewhat less than that of the liquid, showing between crossed nicols mostly second-order colors, and yielding no interference figures in convergent light. Both cinchonine and quinidine have indices lengthwise higher than the liquid, but they may be recognized by immersion of another sample in liquid with index 1.690. Cinchonine shows the index lengthwise equal to that of this liquid; and yields an interference figure with a small axial angle. Quinidine has the index lengthwise equal to, or slightly lower than, the liquid, but its axial angle is large.

Experiments with mixtures and with drugs containing these alkaloids have shown these methods to be of considerable practical value, and application to other groups of substances is planned.

ARSENIC IN SULPHURED FOOD PRODUCTS.

By W. D. Collins.

[ABSTRACT.]

SMALL amounts of arsenic, from one to four parts of arsenic (As_2O_3) per million parts of product, have been found in hops and dried fruits treated with fumes from sulphur which contained arsenic. A number of samples of Japanese sulphur contained from 100 to 500 milligrammes of arsenic (As_2O_3) per kilogramme. It is generally known that sulphur from the largest source of supply in the United States is free from arsenic. A sample from this source, and samples from five other sources in the United States, all proved to be free from arsenic, or to contain less than one milligramme per kilogramme. Producers can avoid contamination of food products with arsenic from sulphur by

burning, for curing the products, only sulphur known to be free from arsenic. If the sulphur cannot be tested, the use of that produced in this country will be an almost certain insurance of freedom from arsenic.

An account of the work, with full details of the analytical methods used, will appear soon in the *Journal of Industrial and Engineering Chemistry*.

THE DETERMINATION OF ARSENIC IN INSECTICIDES BY POTASSIUM IODATE.[3]

By George S. Jamieson.

THE method is based upon the titration of a hydrochloric acid solution of the arsenite with a standard solution of potassium iodate, using a chloroform indicator. The reaction between the arsenic and potassium iodate is represented by the following equation:

$$As_2O_3 + KIO_3 + 2HCl = As_2O_5 + ICl + KCl + H_2O.$$

It was found that there should be at least 11 per cent. of hydrochloric acid present at the end of the titration to prevent the hydrolysis of the iodine monochloride. Cupric and ferric compounds do not interfere with the titration. In the direct titration of insecticides, cuprous and antimonious compounds are oxidized by potassium iodate, as is the case with the iodine titration, but fortunately these compounds occur only in small amounts.

In order to apply this method to the determination of the total arsenic the official distillation process of the Association of Official Agricultural Chemists was employed to obtain all of the arsenic in the arsenious condition. The distillate was diluted to 500 c.c. and aliquots of 100 c.c. were titrated with potassium iodate without the further addition of hydrochloric acid unless more than 25 or 26 c.c. of the standard solution were required.

The investigation showed that arsenic could be satisfactorily determined by this method. Furthermore, the very definite and remarkably sharp end point, the great stability of the potassium iodate solution, and the readiness with which it can be prepared, recommend the method in preference to the iodine titration.

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[3] *J. Ind. and Eng. Chem.*, March, 1918.

THE FRANKLIN INSTITUTE.

(*Proceedings of the Stated Meeting held Wednesday, March* 20, 1918.)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, March 20, 1918.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 6.

Reports of progress were presented by the Committee on Science and the Arts and the Committee on Library.

The President announced that the next business of the meeting would be the presentation of the Edward Longstreth Medal of Merit to Mr. Levi Talbot Edwards, and recognized Dr. H. Jermain Creighton, chairman of the Committee on Science and the Arts. Doctor Creighton made a brief statement in reference to the invention of the Air-Lift and its uses, and introduced the inventor, Mr. Edwards, who had been recommended by the Committee on Science and the Arts for the award of the Edward Longstreth Medal of Merit for his device. The President then presented the medal and accompanying certificate to Mr. Edwards, who thanked the Institute for the recognition bestowed upon him.

Mr. F. W. Sperr, Jr., Chief Chemist, The H. Koppers Company, Pittsburgh, Pa., then presented the paper of the evening, entitled "Characteristics of American Coals in By-products Coking Practice." The speaker called attention to the rapid replacement of the old beehive coke oven by the modern by-product oven, and some of the interesting economic developments in the coal industry which result from this change. The behavior of various American coals in the by-product oven was described in detail, and results of studies in this connection were presented. The coking property of coal and some of the important phenomena of the coking process were discussed. Attention was also given to the behavior of various typical coking coals in the by-product ovens, as well as the practical results of coking such coals, with respect to the yields of the various by-products, and the quality of the coke produced. The subject was illustrated by lantern slides and specimens.

After a brief discussion, the thanks of the meeting were extended to the speaker.

Adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

MEMBERS OF THE FRANKLIN INSTITUTE WHO ARE IN THE ACTIVE MILITARY OR NAVAL SERVICE OF THE UNITED STATES GOVERNMENT.

Name and rank	Branch of service	Location
Allen, Henry B., 1st Lieut.	Ordnance Dept., U. S. R.	France
Anderson, Geo. L., Colonel	Board of Ordnance & Fortification	Washington
Atherholt, Gordon Meade	Aeronautical Mechanical Engineer, Signal Corps	Washington
Atterbury, W. W., Brig. Gen.	Director-General of Railways	France
Bacon, Raymond Foss, Lt. Col.	Head of Chemical Service Section, U.S.N.A.	France
Barnhart, G. Edw.	Aeronautical Mechanical Engineer, Signal Corps	Fairfield, Ohio
Barr, John H., Major	Ordnance Reserve Corps	Washington
Barrett, C. D., Major	9th Engineers	
Bartow, Edward, Major	U.S.N.A. Sanitary Corps	France
Booz, Horace Corey, Colonel	Railroad Transportation Corps, U.S.N.A.	France
Bostwick, John Vaughan, Capt.	O.R.C., 315th Infantry	Camp Meade
Breed, George, Lieutenant	Fleet Naval Reserve, U.S.N. R.F.	New York
Bunting, C. M., Colonel	E.O.R.C., U.S.A.	France
Cadwalader, Governeur, Major	Ordnance Dept., U.S.R.	
Caldwell, E. W.	Medical Officers' Reserve Corps	
Capps, W. L., Rear Admiral	Chief Constructor, U.S.N., Bureau of Construction and Repair	Washington
Carty, John J., Colonel	Signal Corps, U.S.A.	
Chance, Edwin M., Capt.	Ordnance Dept., U.S.R.	Washington
Clark, Beauvais, Sergeant	108th Field Artillery	Camp Hancock
Clark, E. L., 1st Lieut.	Signal Corps, 401st Telegraph Battalion	Camp Devens
Clark, Theobald F., Capt.	Field Artillery	Fort Sill
Clark, Walton, Jr., Capt.	Field Artillery	Fort Sill
Cornelius, John C., 1st Lieut.	Coast Artillery, U.S.N.A., 13th Company	Sandy Hook
Cottrell, Jas. W., Private	Instruction Section, Ordnance Dept., U.S.A.	Peoria, Ill.
Cowan, Henry B., Sergeant, 1st Class	Co. D., First Telegraph Battalion, Signal Reserve Corps	France
Crampton, George S., Major	Director of Field Hospitals, 28th Div.	Camp Hancock
Cushman, A. S., Lieut. Col.	Ordnance Dept., U.S.N.A.	Frankford Arsenal
Detwiler, Jas. G., 1st Lieut.	Infantry, U.S.R.	Fort Logan H. Roots
Eckert, S. B., Lieut.	Commander 9th Aero Squadron	France
Elliott, Henry M., 1st Lieut.	Ordnance Dept., U.S.R.	Western Cartridge Co.
Emerson, Geo. H., Colonel	In charge of Russian Railway Service Corps	Japan
Felton, Samuel M.	U. S. Director-General of Railways in connection with Expeditionary Force	Chicago
Ferguson, Walter B., Private	21st Co., 154th Depot Brigade	Camp Meade

Name and rank	Branch of service	Location
Fraser, Persifor, Ensign	U.S.N.R.F.	League Island
Gardner, H. A., Senior Lieut.	Naval Flying Corps	Washington
Gfrörer, A. H., 1st Lieut.	Ordnance Dept., U.S.R.	Washington
Gibbons, Joseph E., Private	Co. D., 103rd Engineers	Camp Hancock
Glendinning, Robt. E., Major	Aviation Section, Signal Corps	Overseas
Gribbel, W. G., Captain	Co. A., 30th Engineers, U.S.R. (Gas and Flame)	France
Griest, Thos. S., 1st Lieut.	1st Telegraph Battalion, Signal Corps, U.S.A.	France
Hall, R. T., Rear Admiral	U. S. Navy, Inspector of Machinery	Cramps' Shipyard
Hodges, Austin L., Capt.	Ordnance Dept., U.S.R., Experimental Officer on Artillery Ammunition	Frankford Arsenal
Howson, Richard, Sergeant	306th Ambulance Corps	Camp Meade
Ives, H. E., Captain	Signal Corps, U.S.A.	Washington
Jones, Jonathan, Captain	E.O.R.C., 23rd Engineers	Camp Laurel
Karrer, Enoch, Private	5th Company, 2nd Battalion 154th Depot Brigade	Camp Meade
Kennedy, M. C., Colonel	Deputy Director General of Transportation	France
Kent, S. Leonard, Jr., 2nd Lieut.	5th Engineers	Camp Lee
Kingsbury, E. F., 1st Lieut.	Aviation Section, S.O.R.C., Dept. of Science and Research	Washington
LeBoutillier, H. W., Private	Unit No. 10, Pennsylvania Hospital	France
Lichtenberg, Chester, 1st Lieut.	Engineer Reserve Corps, U.S.A.	Washington
Longstreth, Chas., Lt. Commander	U.S.N.R.F.	Philadelphia
McCoy, John F.	Aviation Section, Signal Corps	Princeton
MacLean, Malcolm R., 1st Lieut.	Co. 9, Officers' Reserve Corps	
Martin, Thos. S., 1st Lieut.	Ordnance Dept., U.S.R.	Washington
Masters, Frank M., Major	Ordnance Dept., U.S.R.	Washington
Maxfield, H. H., Lieut. Col.	19th Railway Engineers, U.S.N.A.	
Mershon, Ralph D., Major	E.O.R.C., U.S.A.	New York
Miller, Fred. J., Major	Ordnance Reserve Corps	Centre Bridge, Penna.
Owens, Major R. B.	Signal Corps	France
Parrish, T. R., 1st Lieut.	Signal Corps	Washington
Reber, Samuel, Colonel	Signal Corps, U.S.A.	New York
Richardson, Chas. E., 1st Lieut.	30th Engineers, U.S.R. (Gas and Flame)	France
Spackman, Henry S., Major	Engineer Officers' Reserve Corps	France
Spruance, W. C., Jr., Lt. Col.	Ordnance Dept., National Army	Chevy Chase Md.
Squier, Geo. O., Major General	Chief Signal Officer, U.S.A.	
Stanford, H. R., Civil Engineer	U. S. Navy	Boston
Thomas, Geo. C., Jr., Captain	Aero Service Squadron 96, Aviation Section, Signal Corps	France
Tilghman, B. C., Captain	A.D.C., 28th Div. Headquarters, U.S.A.	
Vogleson, J. A., Major	Sanitary Corps (Surgeon General's Dept.)	Fort Oglethorpe
Wagner, Fred. H., Major	Ordnance Reserve Corps, Nitrate Division	Washington
Wagner, Fred. H., Jr. Sergeant	Co. E., 304th Engineers	Camp Meade

Name and rank	Branch of service	Location
Wetherill, W. C., Ensign	U. S. Navy	
Widdicombe, R. A., Major	C.Q.M., Chemical Plant No. 4	Saltville, Va.
Wood, Edw. R., Jr., Captain	18th Field Artillery, U.S.N.A.	El Paso, Texas
Worrell, Howard Sellers	3rd Officers' Training Camp	Fortress Monroe
Wyckoff, A. B., Lieut.	U. S. Navy	Ontario, Cal.
Yale, A. W. Major	Medical Reserve Corps, Gas Division	Camp Kearney
Yorke, George M., Major	Signal Corps, U.S.R.	New York

MEMBERS DOING CIVILIAN WORK FOR THE UNITED STATES GOVERNMENT

Name	Appointment	Location
Akeley, Carl E.	Consulting Expert of Mechanical Devices, War Department	Washington
Anderson, Robt. J.	Engineer of Tests of Ordnance, War Dept., U.S.A.	Brier Hill Steel Co.
Balls, William H.	Ships Draughtsman	Phila. Navy Yard
Bancroft, Joseph	Secretary, Local Board No. 1	Wilmington
Baskerville, Charles	Working with Bureau of Mines, Ordnance Dept. (Gas Warfare, Shells, etc.)	New York
Bodine, Samuel T.	Vice-Chairman, District Exemption Board, No. 1, Eastern Judicial District of Penna.	Philadelphia
Brown, Lucius P.	Federal Milk Commission	New York
Burnham, George, Jr.	Dept. of Civilian Service and Relief, Public Safety Committee of Pennsylvania	Philadelphia
Charles, Bernard S.	Ordnance Inspector, U. S. Navy	Allentown, Pa.
Comey, Arthur M.	Chairman, Sub-Committee on Explosives, Chemistry Committee, National Research Council	Chester, Pa.
Condict, G. Herbert	Naval Consulting Board, Member Committee of Examiners	Plainfield, N. J.
Cooke, Morris L.	Chairman, Storage Committee of Munitions Board; Member on Staff, Emergency Fleet Corporation	Washington
Cope, Thomas D.	National Research Council	Washington
Day Charles	Member of Army War Council	Washington
Delano, Frederic A.	Member of Federal Reserve Board	Washington
Dickie, G. W.	Chief Inspector, U. S. Shipping Board, Moore & Scott Shipyard	Oakland, Calif.
Douredoure, B. L.	Student at Franklin Institute Radio School	Philadelphia
Dunn, Gano	Chairman, Engineering Committee, National Research Council	New York
Garrison, Frank Lynwood	Chairman, U. S. Manganese Commission	Philadelphia
Gilpin, Francis H.	Mechanical Engineer, Research Section, Picatinny Arsenal	Dover, N. J.
Halberstadt, Baird	Federal Fuel Administrator for Schuylkill Co., Penna.	Pottsville

Name	Appointment	Location
Hoskins, Wm.	Consulting Chemist, Advisory Committee, Bureau of Mines; Associate Member, Naval Consulting Board	Chicago
Hyde, Edward P.	National Research Council, Sub-Committee on Monocular vs. Binocular Field-Glasses (Chairman).	Cleveland
Insull, Samuel	Chairman, Illinois State Council of Defense	Chicago
Kennelly, A. E.	Conducting special course in radio-engineering for the U. S. Signal Corps, in conjunction with Prof. E. C. Chaffee	Harvard Univ.
Lloyd, E. W.	Asst. Secretary, Illinois State Council of Defense	Chicago
Lucke, C. E.	Civilian Director, U. S. Navy Gas Engine School	Columbia Univ.
Merrick, J. Hartley	Director, Bureau of Camp Service, Penna. Div., American Red Cross	Philadelphia
Milne, David	Treasurer, American Red Cross General Hospital No. 1	Philadelphia
Morris, Effingham B.	Treasurer, Committee of Public Safety, State of Pennsylvania	Philadelphia
Nichols, Carroll, B.	Fuel Administration	Washington
Nichols, Wm. H.	Committee on Chemicals, Advisory Council of National Defense, Consulting Chemist, Bureau of Mines	New York
Penrose, R. A. F., Jr.	Member of Geology Committee of the National Research Council	Philadelphia
Rapp, Isaiah M.	Special Investigator of Weights and Measures for the U. S. Food Administration	Norman, Oklahoma
Rautenstrauch, Walter	Committee of the National Research Council	New York
Richards, Joseph W.	Member of Naval Consulting Board	So. Bethlehem, Penna.
Robins, Thomas	Member and Secretary of the Naval Consulting Board	New York
Sperry, Elmer A.	Member of Naval Consulting Board	Brooklyn, N.Y.
Sprague, Frank J.	Member of Naval Consulting Board, Chairman, Committee on Electricity and Shipbuilding	
Stradling, George F.	Recruiting for Aviation Section, S.O.R.C.	Philadelphia
Swenson Magnus	Federal Food Administrator for Wisconsin; Chairman, State Council for Defense	Madison, Wis.
Talbot, Henry P.	Member of Advisory Board, Bureau of Mines (Gas Defense)	Cambridge, Mass.
Thomson, Elihu	National Research Council in coöperation with Council of National Defense	Swampscott, Mass.

Please send additional information and corrections to the Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, March 6, 1918.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 6, 1918.

DR. H. JERMAIN CREIGHTON *in the Chair.*

The following report was presented for first reading:

No. 2709.—The Fahy Permeameter.

The following reports were presented for final action:

No. 2656.—Automatic Operation of Water Gas Sets. Recommended that Edward Longstreth Medals of Merit be awarded to John Hawley Taussig, of Philadelphia, Pa., and to Charles Franklin Zeek, of Pensacola, Fla., for their inventions embodied in this device.

No. 2690.—Havard Coal Meter. Recommended that the Certificate of Merit be awarded to Oliver D. Havard, of Allentown, Pa.

GEORGE A. HOADLEY,
Acting Secretary.

SECTIONS.

Sections of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, February 14, 1918, at 8 o'clock, with Mr. G. H. Clamer in the chair. The minutes of the previous meeting were read and approved.

C. W. Kanolt, Ph.D., of the Bureau of Standards, Washington, D. C., delivered a lecture on "Refractory Materials and High-temperature Measurements." A description was given of the measurement of high temperatures by means of thermocouples, resistance thermometers, and optical and radiation pyrometers. A report was given of research on various refractories and on the resistance of structures and structural materials to fire. The lecture was illustrated with lantern slides, and with samples of refractories and of apparatus used in high-temperature measurements.

The paper was discussed by Doctors Northrup and Kanolt, Professor Snyder, Mr. Fulweiler, and others. On motion of Doctor Hoadley, a vote of thanks was extended to Doctor Kanolt, and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

Sections of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, February 28, 1918, at 8 o'clock, with Dr. Harry F. Keller in the chair. The minutes of the previous meeting was approved as read.

F. E. Wright, Ph.D., Captain of Ordnance, U. S. R., of the Geophysical Laboratory of the Carnegie Institution of Washington, delivered a lecture on

"The Production of Optical Glass for Military Purposes," describing the increase during the past year in both the quality and the quantity of American optical glass as the result of coöperation between the Geophysical Laboratory and the Bausch & Lomb Optical Company. A summary was given of the raw materials used, the process of manufacture, and the tests applied to the product. The communication was discussed by Doctors Stradling, Alleman, and Barton, Messrs. Benoliel and Patterson, Captain Wright, and others. A vote of thanks was extended to Captain Wright.

Mr. W. N. Jennings then described "The Rapid-fire Construction of the Cantonment at Camp Dix," showing a series of lantern slides of the cantonment taken by himself at various stages of its construction.

The meeting then adjourned.

JOSEPH S. HEPBURN,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, March 13, 1918.*)

RESIDENT.

PROF. LEO LOEB, Mechanical Engineer, Day & Zimmermann, Inc., 611 Chestnut Street, Philadelphia, Pa.

MR. A. SAUNDERS MORRIS, Mechanical Engineer, Eighteenth Street and Allegheny Avenue, Philadelphia; and for mail, Haverford, Pa.

MR. JAVIER RESINES, Industrial Chemist, Eighteenth Street and Allegheny Avenue; and for mail, Hotel Stenton, Philadelphia, Pa.

NON-RESIDENT.

MR. LEWIS MARVIN DRAKE, Experimental Scientist, West Fairview Avenue, Daytona, Florida.

PROF. CLINTON NEVIUS LAIRD, Missionary, Educator, Chemist, Canton Christian College, Canton, China; and for mail, 3343 North Bouvier Street, Philadelphia, Pa.

LIBRARY NOTES.

PURCHASES.

BALL, SIR R. S.—Treatise on the Theory of Screws. 1900.

BYERLY, W. E.—Introduction to the Use of Generalized Coördinates in Mechanics and Physics. 1916.

COOPER, G. S.—By-product Coking. 1917.

CROFT, TERRELL.—Practical Electricity. 1917.

HATCHER, J. S., WILHELM, G. P., and MALONEY, H. J.—Machine Guns. 1917.

LITTLE, H. F. V.—Aluminium and Its Congeners, Including the Rare Earth Metals. 1917.

Moody's Manual of Railroad and Corporation Securities, vol. 19, part 1. 1918.
MORSE I. H.—Calculations Used in Cane-sugar Factories. 1917.
OSTWALD, WILHELM.—Fundamental Principles of Chemistry. 1917.
THORINGTON, JAMES.—Refraction of the Human Eye. 1916.
TSCHAPPAT, W. H.—Text-book of Ordnance and Gunnery. 1917.

GIFTS.

Ajax Manufacturing Company, Reference Book and Catalogue No. 15, and Bulletin No. 31. Cleveland, Ohio, no dates. (From the Company.)
Alberger Pump and Condenser Company, Bulletin No. 17. New York, 1913. (From the Company.)
Allis-Chalmers Manufacturing Company, Catalogue No. 106, Cyanide Plants and Equipment. Milwaukee, Wis., 1917. (From the Company.)
American Clay Machinery Company, American Standard Foundry Pan for Mixing or Grinding Sand for Gray Iron and Steel Foundries. Bucyrus, Ohio, no date. (From the Company.)
American Hard Rubber Company, Acid Pumps, Pipe and Fittings. New York, no date. (From the Company.)
American Institute of Mining Engineers, Transactions, vol. lvi. New York, 1917. (From the Institute.)
American Steel and Wire Company, Aerial Tramways. Chicago, Ill., 1917. (From the Company.)
American Well Works, Catalogue No. 149, Centrifugal Pumps. Aurora, Ill., 1917. (From the Works.)
Amherst College, Catalogue, 1917–18. Amherst, Mass., 1917. (From the College.)
Automatic Buffing Machine Company, Inc., Catalogue D. Buffalo, N. Y., no date. (From the Company.)
Bond Foundry and Machine Company, Catalogue No. 38, Power Transmitting Machinery. Manheim, Pa., 1917. (From the Company.)
Bond, Harold L. Company, Atlantic Pumping Engines for Contractors, Municipalities, and Corporations. Boston, Mass., no date. (From the Company.)
Butterfield and Company, Inc., Catalogue No. 16, Taps, Dies, Reamers, and Screw Plates. Derby Line, Vt., no date. (From the Company.)
Cambridge, Mass., Water Board, Annual Report, April 1, 1916, to April 1, 1917. Cambridge, 1917. (From the Board.)
Canada Department of Mines, Geological Survey, Memoir 99, Road Material Surveys in 1915, by L. Reinecke; Memoir 102, Espanola District, Ontario, by T. T. Quirke. Ottawa, 1917. (From the Survey.)
Canada Minister of Public Works, Report for the Fiscal Year Ended March 31, 1917. Ottawa, 1918. (From the Minister.)
Card, S. W. Manufacturing Company, Catalogue No. 28, Taps, Dies, Screw Plates. Mansfield, Mass., no date. (From the Company.)
Chicago Bureau of Public Efficiency, The Water Works System of the City of Chicago. Chicago, Ill., 1917. (From the Bureau.)

Connelly Boiler Company, Connelly Water Tube Steam Boilers. Cleveland, Ohio, no date. (From the Company.)

Cooper, C. and G. Company, Catalogue of Cooper Gas Engines, and Bulletin No. 54. Mount Vernon, Ohio, 1912. (From the Company.)

Curtis & Curtis Company, Pipe Cutting and Threading Machinery. Bridgeport, Conn., no date. (From the Company.)

Eclipse Fuel Engineering Company, Heat Treatment of Steel in Gas Furnaces, and the Heat Treatment of High-speed Steel, by Garnet W. McKee. Rockford, Ill., 1918. (From the Company.)

Eureka Machine Company, Eureka Concrete and Motor Mixers. Lansing, Mich., no date. (From the Company.)

Falls Machine Company. Falls Automatic Engine Stop. Sheboygan Falls, Wis., no date. (From the Company.)

Files Engineering Company, Inc., Files Hand Stoker. Providence, R. I., no date. (From the Company.)

Ganschow, William Company, Catalogue No. 26, Ganschow Gears. Chicago, Ill., 1915. (From the Company.)

Gilbert & Barker Manufacturing Company, Catalogue B, Gas Furnaces. Springfield, Mass., 1912. (From the Company.)

Gisholt Machine Company, Increasing Production with Gisholt Machines. Madison, Wis., no date. (From the Company.)

Greenfield Tap and Die Corporation, Bulletin No. 1, How to Measure Screw Threads; and Wells Self-opening Die. Greenfield, Mass., 1917. (From the Corporation.)

Hanson & Van Winkle Company, Catalogue No. 21, Electro-plating and Polishing Supplies. Newark, N. J., 1917. (From the Company.)

Harper and Brothers, The Harper Centennial, 1817–1917. New York, 1917. (From the Publishers.)

Helm Brick Machine Company, Concrete for Beauty, Adaptability, and Permanence. Cadillac, Mich., no date. (From the Company.)

Heræus Le Chatelier Pyrometer, Catalogue P, and Facts Worth Knowing About Pyrometers. New York, 1915. (From Mr. Charles Engelhard.)

Hoskins Manufacturing Company, Bulletins Nos. 1, 3, 3-A, 8, 10, and 12. Detroit, Mich., 1915–17. (From the Company.)

International Heater Company, Catalogues of Boilers and Furnaces. Utica, N. Y., 1910–17. (From the Company.)

Kennedy Valve Manufacturing Company, General Catalogue and Price List, 1916. Elmira, N. Y., 1916. (From the Company.)

Lackawanna Steel Company, Bulletin No. 108, Lackawanna Steel Sheet Piling. Lackawanna, N. Y., 1915. (From the Company.)

Langelier Manufacturing Company, Catalogue of Drilling and Tapping Machines. Arlington, Cranston, R. I., no date. (From the Company.)

LeBlond, R. K. Machine Tool Company, Catalogues, LeBlond Lathes, and Heavy Duty Crankshaft Lathes, and A Lesson in Economics. Cincinnati, Ohio, 1914–17. (From the Company.)

Leland Stanford Junior University, Annual Report of the President for the Twenty-sixth Academic Year Ending July 31, 1917. Stanford University, Calif., 1917. (From the University.)

Lupton's, David, Sons Company, Catalogue No. 9, Service Products; and Air, Light, and Efficiency. Philadelphia, 1916–17. (From the Company.)

McCord Manufacturing Company, Catalogue No. 18, Universal Window Devices. Detroit, Mich., no date. (From the Company.)

Milwaukee Tool and Forge Company, Tools for Service. Milwaukee, Wis., no date. (From the Company.)

Mitchell-Tappen Company, Standardized Metal Caging for Fireproof Buildings. New York, no date. (From the Company.)

Moloch Stoker Company, Catalogue of the Moloch Type "H" Stoker. Chicago, Ill., 1918. (From the Company.)

Mueller, H. Manufacturing Company, Ltd., The Men Behind the Man Behind the Gun. Port Huron, Mich., 1917. (From the Company.)

National Scale Company, The National Factory Systems. Chicopee Falls, Mass., 1917. (From the Company.)

New Jersey State Library, New Jersey Archives, First Series, vol. xxix. Paterson, N. J., 1917. (From the State Librarian.)

Newton Machine Tool Works, Inc., Catalogue No. 49, Newton Slotting Machines. Philadelphia, no date. (From the Works.)

New York Public Service Commission for the First District, Report for the Year Ending December 31, 1916, vol. i. Albany, 1917. (From the Commission.)

New York State University, Department of Education, Elementary Education, Report for the School Year Ending July 31, 1916, by Thomas E. Finegan. Albany, 1917. (From the New York State Library.)

New Zealand Government Statistician, Statistics of the Dominion for the Year 1916, vol. i: Blue Book, Population and Vital Statistics, Law and Crime. Wellington, 1917. (From the Government Statistician.)

North Western Expanded Metal Company, Hand-book for Formless Concrete Construction Using T-rib Chanelath. Chicago, Ill., 1918. (From the Company.)

Ohio Brass Company, Catalogue No. 16. Mansfield, Ohio, 1916. (From the Company.)

Ontario Bureau of Industries, Annual Reports for 1914, 1915, and 1916, parts i and ii. Toronto, 1915–17. (From the Bureau.)

Ontario Bureau of Mines, Twenty-sixth Annual Report, 1917. Toronto, 1917. (From the Bureau.)

Pennsylvania Railroad Company, Instructions Governing the Use of Explosives. Philadelphia, 1913. (From Mr. J. C. Johnson, Superintendent of Telegraph.)

Pennsylvania Society of the Colonial Dames of America, Committee on Historical Research, Forges and Furnaces in the Province of Pennsylvania. Philadelphia, 1914. (From Mrs. James M. Longacre, Chairman.)

Penrose, Charles, Station Safeguarding. Philadelphia, 1916. (From the Author.)

Princeton University, Catalogue, 1917–18. Princeton, N. J., 1917. (From the University.)

Savage Arms Company, Lewis Automatic Machine Gun, Model 1916. Utica, N. Y., 1916. (From the Company.)

Second Pan-American Scientific Congress, Proceedings, vol. vi, Section V. Washington, 1917. (From the Congress.)

Shuster, F. B. Company, Bulletin A, Automatic Wire Straightening and Cutting Machines. New Haven, Conn., no date. (From the Company.)

Smith College, Catalogue, 1917–18. Northampton, Mass., 1917. (From the College.)

Stevens Institute of Technology, Annual Catalogue, 1918–19. Hoboken, N. J., 1918. (From the Institute.)

Sturtevant Mill Company Separator Catalogue No. 77F, and Ring Roll Mill Catalogue No. 79C. Boston Mass., 1917. (From the Company.)

Sweet's Catalogue Service, Sweet's Engineering Catalogue, Fourth Annual Edition. New York, 1917. (From the Service.)

Trussed Concrete Steel Company, Kahn Road Book, and Kahn Building Products, Seventh Edition. Youngstown, Ohio, 1916. (From the Company.)

U. S. Coast and Geodetic Survey, Annual Report of the Superintendent for the Fiscal Year Ended June 30, 1917. Washington, 1917. (From the Survey.)

United States Electrical Tool Company, Catalogue No. 16, Portable Electrical Tools. Cincinnati, Ohio, 1917. (From the Company.)

University of Maine, Catalogue, 1917–18. Orono, 1917. (From the University.)

Walter Concrete Machinery Company, Inc., Walter Concretile, A Roof for All Time. Indianapolis, Ind., no date. (From the Company.)

Westinghouse Electric and Manufacturing Company, Catalogue 8-E, Industrial Heating Apparatus. East Pittsburgh, Pa., 1917. (From the Company.)

Wheeler, C. H. Manufacturing Company, The Radojet Air Pump. Philadelphia, 1918. (From the Company.)

Williams, D. T. Valve Company, Catalogue No. 10, Steam Specialties. Cincinnati, Ohio, 1915. (From the Company.)

Wilmarth & Morman Company, Catalogue No. 107, of Grinding Machinery. Grand Rapids, Mich., no date. (From the Company.)

Witte Engine Works, Catalogue No. 48, How to Judge Engines. Kansas City, Mo., no date. (From the Works.)

BOOK NOTICES.

FINDING AND STOPPING WASTE IN MODERN BOILER ROOMS. By Engineers of the Harrison Safety Boiler Works. Philadelphia, Harrison Safety Boiler Works, 1918. 274 pages, illustrations, tables, diagrams. 12mo. Flexible cloth. Price, $1.

Commercial engineering organizations and manufacturers of engineering specialties in recent times have given a great deal of attention to the publication of the strictly technical side of their interests, and some highly creditable technical literature is now to be found, either in bulletins or in catalogues, primarily issued for the purpose of exploiting the activities or the products

of such firms. The present work is a publication of this type, originally intended as an appendix to the company's catalogue of Cochrane V-Notch Meter, which has grown to require a separate volume. In this handbook the best available contributions of engineers to technical periodicals, engineering societies and government publications have been collected in convenient form for ready reference. Among the latter, the excellent bulletins on the utilization of fuels issued during recent years by the United States Bureau of Mines have been freely drawn upon.

The work is divided into five sections: "Fuels," "Combustion," "Heat Absorption," "Boiler Efficiency," and "Boiler Plant Proportioning and Management." Under these headings a very wide range of information is covered, the subject-matter having been selected with a view to its service to owners, managers, engineers, and firemen in increasing and maintaining boiler-plant economy. The book has been compiled by George H. Gibson, assisted by Mr. Percy S. Lyon. The proofs were read by Mr. Henry Kreisinger, who conducted for the United States Bureau of Mines many of the investigations quoted in the text.

LUCIEN E. PICOLET.

PUBLICATIONS RECEIVED.

The Taylor System in Franklin Management Application and Results, by Major George D. Babcock, in collaboration with Reginald Trautschold, M.E., with a foreword by Carl G. Barth. 245 pages, illustrations, plates, tables, diagrams. New York, Engineering Magazine Company, 1917. Price, $3.

American Lubricants from the Standpoint of the Consumer, by L. B. Lockhart, consulting and analytical chemist. 236 pages, illustrations, 8vo. Easton, Pa., The Chemical Publishing Company, 1918. Price, $2.

Chemical French: An introduction to the Study of French Chemical Literature, by Maurice L. Dolt, Ph.D. 398 pages, 8vo. Easton, Pa., The Chemical Publishing Company, 1918. Price, $3.

Canada, Department of Mines, Mines Branch: Summary Report for the Calendar Year Ending December 31, 1916. 183 pages, illustrations, plates, tables, 8vo. Ottawa, King's Printer, 1917. Price, 25 cents.

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Explosives Law and Negative-making. ANON. (*The Inland Printer*, vol. 60, No. 5, p. 629, February, 1918.)—Now that the government is demanding that photo-engravers take out a license and deposit a bond before they can use alcohol and nitro-cellulose for making collodion, some of the discarded processes of negative making have been under consideration as possible substitutes. Many of these tried-out processes were too slow, but with the aid of modern electric lighting equipment and quick-working lenses they might prove of value until the restrictions on the use of collodion materials are removed.

There are a number of early processes that might be improved in the light of modern knowledge and put into practical use, such as the calotype and Greenlaw's process, which furnished negatives on paper and which have their counterpart in some of the modern bromide papers. The great trouble with them is the difficulty of reversing unless a prism is used, which doubles the length of exposure. Negatives on glass supports might be made with albumen or gelatin as the medium of holding the sensitive salts, and here again comes difficulty in stripping the negatives. Of course, dry plates can be used, either gelatin or collodion, and where the number of negatives required is not great they are really economical. It is a splendid opportunity for the marketing of a reliable collodion dry plate, as a wet-plate operator can handle it so much more satisfactorily than a gelatin plate. In fact, the situation may bring out an entirely new method of negative-making. It is suggested that the term "nitro-cellulose" be not used, or "gun-cotton" either, as they sound too explosive. The proper word is "pyroxylin" for the soluble cotton used in collodion. Securing a license and giving bond for the continued use of collodion is, however, a more practicable means of insuring satisfactory results.

CURRENT TOPICS

A New Standard of Current and Potential. C. F. ALCUTT. (*Proceedings of the American Institute of Electrical Engineers,* vol. 37, No. 2, p. 83, February, 1918.)—The increasing use of potentiometers in commercial service, especially in connection with the measurements of temperature by means of thermocouples, makes it very desirable to secure a substitute for the standard cell usually required by these instruments. The serious shortage of standard cells caused by the war has emphasized this need. Furthermore, it is being recognized that it is poor economy to use a costly precision standard in a commercial potentiometer which reads to three significant figures at the most.

The new standard which is proposed as a substitute for the standard in certain classes of direct-current measurements is essentially a Wheatstone bridge which will balance for but one value of the current. The device consists of a Wheatstone bridge comprising three constant resistances, and a fourth element whose resistance is a function of the current flowing through it. In practice the resistance element consists of an evacuated glass bulb which encloses a fine filament of material having a relatively high temperature-coefficient of resistivity. The practicability of the device depends on securing a variable resistance having the desired current-resistance characteristics, together with a high degree of permanence. A bridge of this type was designed to balance with a current of 20 milliampères, and having just one volt potential difference when the bridge is balanced. The work done in connection with the development of this new standard has demonstrated that it may be relied upon to maintain an accuracy of plus or minus 0.1 per cent.

A Patent Abuse. ANON. (*Journal of Industrial and Engineering Chemistry,* vol. 10, No. 3, p. 2, March, 1918.)—The exigencies of the war period have led to feverish activity in many laboratories in attempts to carry out processes described in the literature and in patent specifications, chiefly in the field of organic chemistry. Within the past year we have frequently been apprised by chemists of the lack of success in the preparation of compounds by following directions, even by most careful attention to the minutest details, in the official records. Men who have experienced this difficulty stand so high that no question of lack of skill and technique can be involved, and we are forced to the conclusion that deliberate misrepresentation has been made, especially in the case of certain foreign patents. If this is true, it is extremely regrettable that the

literature of chemistry is clogged with such deceit; in the case of patent specifications it is reprehensible, in that a matter of perjury is involved. The demonstration of such falsity would immediately invalidate the patent, but this is a tedious process, necessitating a great amount of laboratory work and expense and loss of time in litigation.

Our patent system should be protected against impositions. This might be accomplished in one of at least three ways: *First*, the Patent Office might test the good faith of all applicants for chemical patents by making greater use of existing government laboratories. It is doubtful, however, in view of the work already engaging the attention of these Federal laboratories, whether a further tax upon their courtesy would be justifiable. *Second*, the Patent Office might be provided with a control laboratory of its own. The varied character of the applications for patents covering all fields of chemistry would necessitate a large, efficiently manned laboratory. This would entail considerable expense, nevertheless it would be an expenditure operating for the benefit of the entire country. *Third*, the Patent Office might require of the applicant a laboratory demonstration of the correctness of the specifications. This would place the burden of the proof upon the inventor, but would work no hardship upon organizations having extensive laboratories, though it might affect the man of small means.

Perhaps there are other practicable remedies. Certain it is that the abuse should be eliminated, and the first step toward this end is the demonstration of the correctness of the original premise; namely, that the Patent Office files have been befouled with false declarations. If evidence can be brought together, we are fortunately in position to place it where it will do most good, and we therefore urge all chemists who have been led up a blind alley by following the directions outlined in patents to communicate that fact to this office, designating by number and subject the misleading patent, and supplementing this by a brief exposition of the difficulties encountered. This is more than an invitation, it is an appeal, for nothing can be more vital to the future of the chemical industries than the establishment upon a firm basis of the patent system, whose *raison d'être* is the stimulation of the inventive genius of the nation by affording full protection of the law to those who record with it the truth concerning their discoveries.

The Peat Deposits of the United States. ANON. (U. S. Geological Survey, *Press Bulletin*, No. 358, March, 1918.)—According to the United States Geological Survey, Department of the Interior, the commercial development of the vast peat deposits in the United States would materially relieve our present shortage of fuel. Although peat has never been largely used as fuel in this country because of our abundant supply of coal, which can be more readily

prepared for consumption and in normal times more cheaply brought to the consumer, it has long been used in Europe, where 15,000,000 to 20,000,000 tons are consumed annually in generating heat and power.

The attempts made in this country to manufacture peat fuel on a commercial scale have not been successful, but the failure appears to have been due not to a lack of market for the product, but to the lack of sufficient capital, to the inexperience of the operators, and to preventable engineering errors. It is said that air-dried machine peat, which is but little inferior in calorific value to many grades of lignite coal, can be produced at a cost ranging from 75 cents to $2.50 a ton, the exact figure depending on the size and the efficiency of the plant; and it is believed that in some parts of the country it could successfully compete with other fuels for both domestic and industrial use. It burns with little smoke and ash, and wherever it has been used in this country it has proved very satisfactory and has found ready sale as fast as it has been produced.

The wide interest felt in the larger use of peat in the United States is expressed in recent messages from the governors of Maine and Massachusetts to the legislatures of those states, recommending an investigation of the local deposits of peat and its possible use to relieve the present shortage of fuel. The lack of other fuel in many European countries is now being supplied in part by an increased use of peat. According to United States commerce reports, 216 peat machines were in operation in Norway in 1917, compared with 55 in 1916 and 36 in 1914. Among these were two automatic machines, each costing $13,400, having a daily capacity of 30 to 40 tons of fuel, and requiring only two men for its operation.

Peat consumed in a properly designed gas producer yields gas of good quality and in abundant quantity in comparison with the yield from coal, as well as many valuable by-products. This is perhaps the most effective utilization of peat fuel for generating heat and power, because peat that is to be used in this way does not need to be so carefully prepared nor so thoroughly dried as peat that is to be consumed under steam boilers.

Specific information with regard to the use of peat in gas-producing plants and for other purposes is given in a bulletin prepared under the supervision of the United States Geological Survey but published as Bulletin 16 of the Bureau of Mines, from which copies of it may be obtained.

The Value of Models. ANON. (*Scientific American*, vol. 118, No. 8, p. 168, February 23, 1918.)—At one time a model was considered only as an interesting feature of the museum or the exposition. To-day a model is looked upon as a prerequisite for the undertaking of many an important piece of work. In such case it serves to translate the technical details of orthographic drawings into a miniature of the projected work, thus relieving the mind of the

effort of visualizing the project from the plans in considering the merits of a given arrangement of the component elements of the project.

In the planning of country estates the work of the model maker is of paramount importance. Plans mean next to nothing to the average man, and, though wash-drawings convey a more understandable impression of the subject, the advantages and faults of an undertaking are much more prominently shown in a model from which the relationships of each detail may be at once seized. In the planning of large buildings the model has very definite application. Such buildings as the Woolworth skyscraper had been reproduced in miniature long before the structure raised itself above the crowded sidewalk of Broadway. Model skyscrapers have enabled many a prospective owner to appreciate what he was ordering.

Copper Castings for Electrical Purposes. G. F. COMSTOCK. (*Proceedings of the American Electrochemical Society*, October 4, 1917.)—Before the work of Matthiesson in 1860 the resistance of the usual grades of copper, even in the form of wire, was only about 50 per cent. of the standard which we have to-day. This work by Matthiesson emphasized the importance of eliminating all possible traces of impurities from copper to be used for conducting electricity. For instance, he found the conductivity of copper with 1.6 per cent. zinc to be only about 79 per cent. that of pure copper, both being in the form of wire. With 1.3 per cent. tin it was decreased to about 50 per cent., with 0.1 per cent. aluminum to 76.5 per cent., and with 0.5 per cent. iron to 36 per cent., while only 0.13 per cent. phosphorus decreased the conductivity to 70 per cent., and even traces of arsenic to 60 per cent.

In order to obtain copper wires of high conductivity it is necessary only to start with extremely pure copper bars. Two difficulties are encountered when this is attempted. First, sound castings are almost an impossibility, and, second, the pure metal in the cast condition is too soft and weak to give the best satisfaction in most electrical uses. The difficulty of obtaining sound castings of pure copper is caused by its rapid absorption of oxygen and other gases when it is melted. The gases not only dissolve in the molten metal, but copper oxide is also formed which is held in solution until the metal freezes. The second difficulty of softness and weakness cannot be overcome except by adding some other metal to the copper, thus making it no longer pure, or by giving the casting some mechanical treatment, such as forging, after which it is, properly speaking, no longer a casting.

Zinc is the element most often used for the purpose of deoxidation, thereby producing sound castings fairly easily with the minimum reduction in conductivity. Such castings deoxidized by zinc had a considerably lower conductivity than copper wire, in many cases only about 40 to 50 per cent. Phosphorus and silicon have both been used

in place of zinc, and, while very small quantities of either are normally sufficient, their use is attended by the disadvantage that an excess of either of these elements does more harm to the conductivity than an equal excess of zinc. The use of silicon has for several years been under investigation with promising results; 75 to 85 per cent. conductivity has been obtained for castings deoxidized with silicon.

Two Million More Horsepower from the Niagara River. R. G. SKERRETT. (*Scientific American*, vol. 117, No. 26, p. 489, December 29, 1917.)—According to the estimates of government experts, it is physically possible to develop at Niagara Falls a maximum of 6,500,000 horsepower, but because of international agreement the legal maximum cannot exceed 790,000. As a matter of fact, because of various hampering circumstances, the total energy actually available for commercial service probably does not exceed 550,000 horsepower. The difference between fact and potentiality is the price paid for scenic beauty. The public generally, time and time again, has registered its vigorous protest against any impairment of this natural wonder. Engineers, therefore, have striven to find acceptable solutions of this economic problem, and among the latest is what is known as the Thomson-Porter Cataract project. Additional hydro-electric energy has become an acute national necessity, and Dr. T. Kennard Thomson, the engineering sponsor of the plan, is satisfied that the scheme in question will make it possible to obtain the desired power without in any wise detracting from the charm of Niagara Falls.

Briefly, the fundamental feature of the project is a massive dam rising from the rocky bed of the Niagara River and blocking the gorge from bank to bank at a point a little more than 4½ miles below the famous Cataract and something like 2½ miles south of Lewiston, N. Y., and Queenston, Ontario. By means of this dam the water level would be raised high enough above the present surface of the river to provide an effective head of 90 feet. The local result would be to lower the visible rise of the flanking cliffs by something like one-third, but the new level would merge exactly with the existing water surface at the Falls, and would therefore in no wise change the scenic conditions there. The existing Rapids would, necessarily, be submerged, but the scheme contemplates substitute rapids below the dam that would be equally tumultuous and probably more spectacular.

The hydro-electric installation, that would be made practicable by the building of the proposed dam, would develop quite 2,000,000 horsepower, and one-half of this would be for the United States and the other half for the Dominion of Canada. Assuming a horsepower to call on an average for the consumption of 10 tons of coal a year, the energy so obtained would be equivalent to the conserving of 20,000,000 tons of fuel annually. According to Doctor Thomson's figures, it would cost substantially $100,000,000 and take three years to rear the dam and to build and equip the associate hydro-electric plants for the development of 2,000,000 horsepower.

Tin in Virginia. ANON. (U. S. Geological Survey, *Press Bulletin*, No. 359, March, 1918.)—The United States is almost entirely dependent on foreign countries for its supply of tin. As this metal is a wartime necessity, and as a domestic source of supply is urgently needed, all known deposits of tin ore (cassiterite) in the United States have recently been examined by geologists of the United States Geological Survey, Department of the Interior. One of the most promising of these deposits is in the Irish Creek district, in the eastern part of Rockbridge County, Virginia, near the summit of the Blue Ridge. This deposit was recently examined by H. G. Ferguson, of the United States Geological Survey, which in this research is acting in coöperation with the Virginia Geological Survey. Mr. Ferguson's report has been published as Bulletin XV-A of the Virginia Geological Survey.

The existence of tin ore in the Irish Creek district has been known for many years, and between 1883 and 1893 the deposit there was actively mined. The mining company, however, became involved in litigation as to land titles and abandoned work in 1893. Work on the deposit was never resumed, and the old workings are now caved and heavily overgrown with brush, so that a thorough examination of them is difficult, but what Mr. Ferguson saw in the field and the information he derived from old reports led him to conclude that the deposits along the Blue Ridge in this vicinity offer some promise as a source of tin, both through the systematic working of the known veins and the possible discovery of other deposits.

The cassiterite occurs in quartz veins that cut a granitic rock of peculiar appearance known as a hypersthene granodiorite. The veins do not continue for long distances, and their content of tin is probably very irregular from place to place. Some high-grade ore was found, however, and some tungsten ore occurs with the cassiterite. It is believed that the district is worthy of further investigation.

A copy of the report, Bulletin No. XV-A of the Virginia Geological Survey, may be secured on application to Dr. Thomas Leonard Watson, Director, Virginia Geological Survey, Charlottesville, Va.

Adirondack Gold and Platinum Sands. ANON. (*U. S. Geological Survey Press Bulletin*, No. 345, December, 1917.)—The United States Geological Survey, Department of the Interior, has received during the last few months a number of letters asking about supposed gold and platinum sands in the Adirondack Mountains. It appears that the falsity of the statements concerning the possibility of working these sands commercially has not been made clear, even after 30 years of effort.

In 1910 Dr. J. M. Clarke, the state geologist of New York, said, "The traces of gold found there [in the Adirondacks] do not afford any adequate basis for mining enterprise." This statement was reiterated in a letter from Doctor Clarke to the National Research

Council, dated July 16, 1917, from which the following extract is made:

"Platinum has been known to exist in small quantities in the sands of northern New York, but the amount is imperceptible and determinable only with difficulty. The platinum story is a veritable 'chestnut,' which has grown exceedingly unpalatable with the years. It has had a new birth this year, and I have already sent out notices to various 'investors,' advising caution in regard to the matter. In fact, within the last two months I have sent a carefully prepared statement to every newspaper printed in the state of New York, urging that no attention be given to the present reports as to the alleged new processes of winning gold and platinum from the sands of northern New York. Philadelphia has been the hotbed of some of the worst propaganda regarding gold and silver in New York that this country has known, and I am speaking within limitations in saying that millions of dollars have been wasted upon investment projects in New York, floated by crooked companies claiming to carry on their demonstrations right under the eye of the intending investor. The story of these 'gold crazes'—one after another, first on the east side of the Adirondacks, then on the west side; at the present time in Herkimer and St. Lawrence counties, while the Lewis County craze is not even yet dead—is a perfectly wicked one. . . . I have on my files the whole history of the transactions—sworn affidavits and confessions of copartners in these gold and platinum propaganda—and I have been going through this thing for the last 30 years, so I am speaking with some knowledge."

The following is a copy of the press bulletin mentioned by Doctor Clarke, issued by the State Geological Survey of New York, May 22, 1917:

"Another effort to arouse interest in the alleged gold-mining operations in this state has been brought to the attention of the state geologist, who on several occasions has warned the public against entering into schemes of this sort. The latest venture has its headquarters in Herkimer County, but nearly all sections of the Adirondacks and various other parts of the state have been exploited by promoters of these ill-founded enterprises, which in several instances have entailed very serious financial losses to the deceived investors. As an additional lure the promoters are now advertising that the sands contain platinum, whose value exceeds many times that of gold. The office of the state geologist has been in touch with this matter from the first, and its records show that there has never been any success attained in such workings, which, at best, contain only mere traces of the precious metals."

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